THE TRUTH ABOUT TODAY'S BIODIVERSITY CRISIS (see page 40)

SCIENTIFIC AMERICAN

NOVEMBER 2001 $4.95
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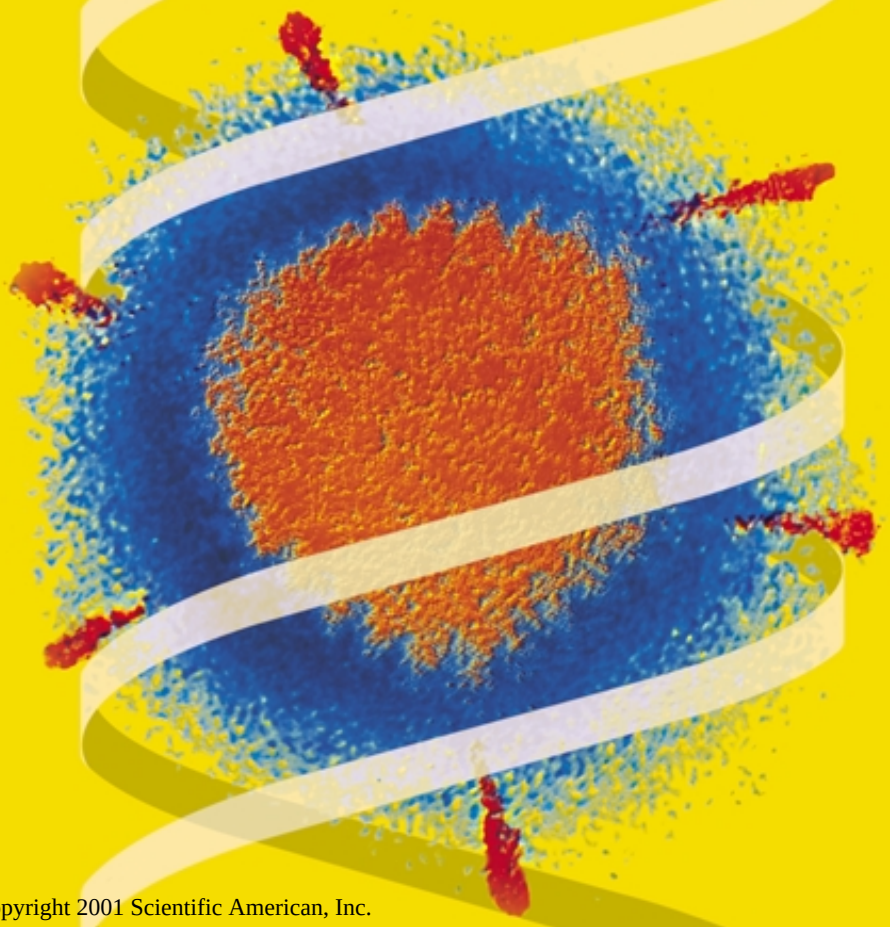
GENETIC TRAPS for VIRUSES

PLUS:

Gravity's Cosmic Lenses

Do Small Classes Really Raise Grades?

The Electronic Paper Chase



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november 2001

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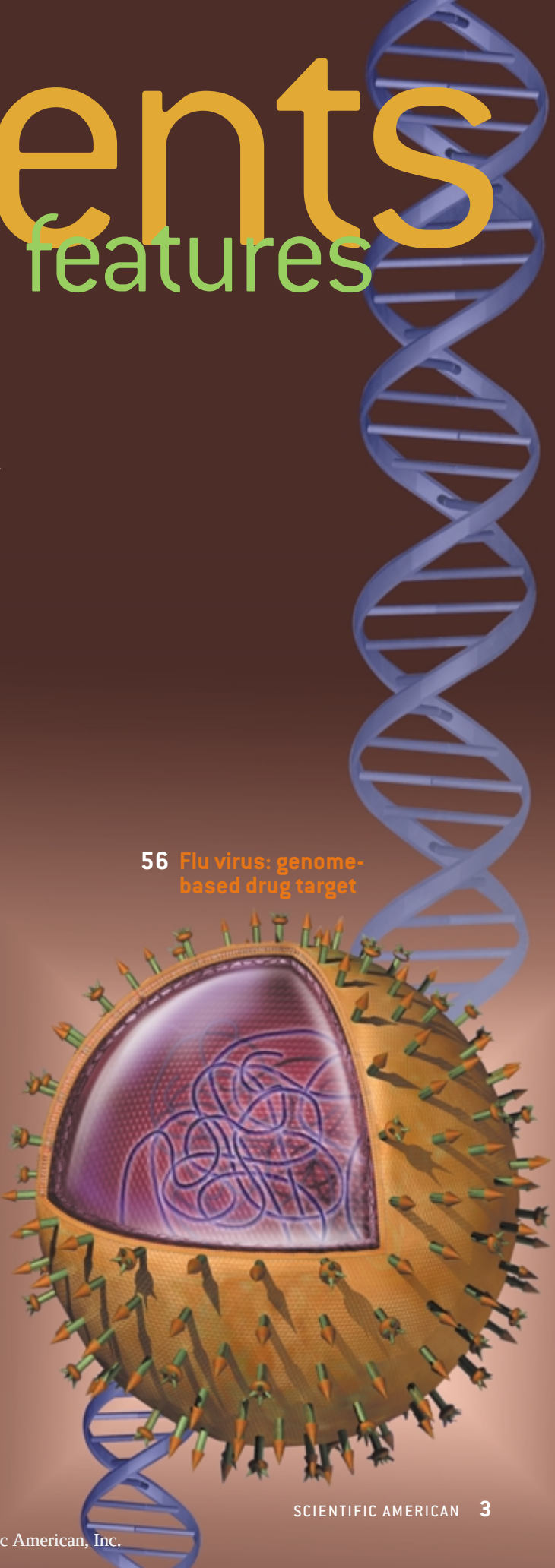
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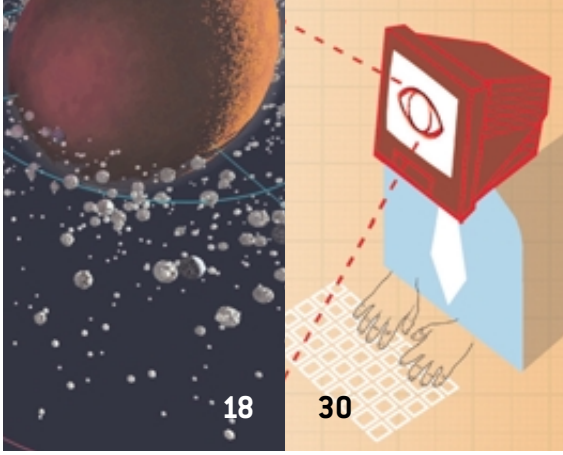
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NOVEMBER 2001

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Invisible Terrorism

Security analysts and others had long worried that the U.S. was vulnerable to a devastating terrorist attack, but nobody really knew how likely it was. September 11 brought us the answer. Suddenly all the nightmare scenarios about mass destruction became frighteningly real. Having felt the horrors of that day, we must now also face the horrors that may yet come.

Few would be worse than biological weapons. Not only is the U.S. unprepared to recover from a biological attack, it might not even recognize that one is occurring until the contagion had already spread. Unlike bombs and nerve gases, bioweapons have finesse: the disease incubation period makes the calamity build slowly and imperceptibly. At first a few people trickle into hospitals. Their symptoms might baffle doctors or mimic those of more common illnesses. By the time health care workers realize what is going on, entire cities could be infected.



DECONTAMINATION TEAM at Fort Drum in New York State.

LEIF SKOOGFORS *Corbis*

Even when authorities recognize an outbreak, they may not realize it was a deliberate attack. The best-known case of bioterrorism on U.S. soil—when devotees of the Bhagwan Shree Rajneesh sprayed salmonella onto restaurant salad bars in Oregon in 1984—was not identified as such until a year later.

Holes in the medical radar keep showing up. A *New England Journal of Medicine* article this past July described the case of a U.S. Army researcher who unknowingly infected himself with glanders, a germ-warfare agent deployed by Germany during World War I. It took months for hospital doctors to diagnose it. A 1996 study looked at deaths from communicable disease in four U.S. states. In 14 percent of the cases, the disease agents were never identified. Nobody blames bioweapons, but it is sobering that so many people die for unknown reasons.

Meanwhile researchers have gained a new appreciation of how easy it is to create bioweapons. In January, Australian researchers announced that a genetic engineering experiment had accidentally created a strain of mousepox that killed most of their lab mice, even vaccinated ones. Recent books describe how researchers in the former Soviet Union may have used similar techniques to endow bubonic plague and anthrax with antibiotic resistance. The *New York Times* recently revealed that U.S. military researchers have been planning a secret program to reproduce the Russian anthrax work, reportedly to prepare a defense.

Some people worry that spending more money on the hypothetical threat of bioterrorism would divert resources from the grim reality of known diseases. But many of the steps taken to combat bioterrorism would also stiffen our defenses against natural scourges. At a conference this past spring at the Stanford University Center for International Security and Cooperation, researchers and policy experts beat the drum for systematic reporting and analysis of disease patterns worldwide, as well as a network of "sentinel laboratories" to assist local public health authorities. Such basic surveillance has long been underfunded.

This nation must also rebuild its stockpile of vaccines and drugs—a new smallpox vaccine is already on the way—and rejoin international efforts to stop the proliferation of bioweapons. In July the Bush administration abandoned negotiations for a treaty to enforce the 1972 Biological Weapons Convention, claiming that site inspections might compromise pharmaceutical trade secrets. That concern is legitimate, but the U.S. has yet to propose an alternative. Meanwhile someone, somewhere, may be preparing to let slip the bugs of war.

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Letters

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"'SOUNDING OUT SNIPERS' [Staking Claims, by Gary Stix] reminded me of an operation in which my father was involved, in France, toward the end of WWI," writes John Keith Wood of Cumbria, England. "The idea was to pick up the sound from an enemy gun emplacement to locate its position. There were six microphones spaced along the line. Three were required for unambiguous triangulation, two more to correct for wind speed and direction, and the last to increase the chance of getting five good signals. The microphone outputs were recorded on 35mm film and the time measurements taken directly from it. The calculations were performed by hand using spreadsheets. My father said that in ideal conditions, which were rare, they could pinpoint an enemy emplacement within five minutes of the first shell that was fired."



Other July letters—including one that arrived on stationery bearing the embossed legend *Even now, I know what you are thinking!*—may be found below.

GETTING SLEEPY—BUT NOT RICH

Those who question hypnosis ["The Truth and the Hype of Hypnosis," by Michael R. Nash] do so because any behavior that has supposedly been produced in a hypnotic state has also been produced outside of such a state. Indeed, my offer of $100,000 to anyone who could prove the existence of a hypnotic state has been challenged only once, unsuccessfully, in a court of law.

There is no such thing as hypnosis, but there is the power of suggestion, a phenomenon that exists in many aspects of our waking life. The time involved and the interaction between hypnotist and subject are the key factors in generating belief.

THE AMAZING KRESKIN
West Caldwell, N.J.

NASH REPLIES: As is often the case with the seemingly grand gestures of entertainers such as Kreskin, there is less to his offer than meets the eye. Empirically based models of hypnotic response long ago abandoned the notion of hypnosis as a state that uniquely enables people to perform feats that are otherwise impossible. Among the scientific community, terms like "state" and "trance" are no longer current as explanatory constructs. Kreskin's money is secure.

Similarly, it is perfectly fine to construe hypnosis as a type of suggestion as long as one understands that there are many other types of suggestion and suggestibility (for example, gullibility, persuadability, interpersonal dependence and placebo response) that are distinct and apparently unrelated to hypnotic response and hypnotizability.

WHEN SPORTS FANS ACT LIKE PHOTONS

In "Frozen Light," Lene Vestergaard Hau writes about slowing and even freezing light. In some ways, talk of slowing and freezing is misleading. The physical speed of the photons that constitute the light is always precisely *c*, the speed of light in a vacuum. Any other speed, or freezing, refers to the phase, or the patterns in the electromagnetic field created by the photons. The situation is analogous to a large crowd of runners always running at precisely the speed *c*. While running, they may perform a backward "wave" like sports fans in a stadium—it is the wave, not the runners, that may be slower than *c* or even stationary.

ZVI SCHREIBER
Jerusalem

The photons that are said to be stopped are in fact destroyed entirely. Imagine a car that enters a garage at noon. The car is entirely disassembled, but the instructions on how to build the car remain intact. Then, perhaps days later, the car is reassembled using new parts and emerges from the rear door. Would one claim that the car was merely slowed or stopped? It isn't even the same car exiting as went in.

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Even in normal materials, light is merely captured and new light reemitted.

LAWRENCE R. MEAD
Department of Physics
University of Southern Mississippi

HAU REPLIES: A pulse of light is made up of a collection of plane waves, a little like Schreiber's runners. The plane waves in our slow-light system travel with a range of phase velocities very close to the speed of light in a vacuum. These waves add up to produce a pulse that travels at a slower speed (like Schreiber's "wave"). It is almost as if the runners at the front disappear after they do their part of the wave and new ones appear at the rear to carry it on.

Mead's rebuilt car will be readily distinguishable from the original by examining the parts closely. Photons in the same quantum state, however, are utterly identical; they carry no serial numbers to tell them apart. As Mead mentions, even light passing through an ordinary material is captured and reemitted. Do we say that a window emits a new ray of sunshine or that the ray has passed through the glass?

THE REAL FLIPPER EFFECT

Gordon Gallup and Daniel Povinelli ["The Flipper Effect," by Philip Yam, News Scan] are correct in reminding us of the high threshold of proof needed for animal self-awareness. At this point, it is the research, not the dolphins, that seems limited. Dolphins can never, by definition, pass Gallup's ingenious primate mirror-mark test, because they can't be anesthetized and don't have arms. This leads researchers to a series of approximations that are imperfect but that, taken together, bring us closer to certainty.

We have often observed dolphins "adorning" themselves with flotsam and posturing directly in front of mirrors. One might pose alternative explanations such as "repetitive spontaneous sustained elaborate contingency checking" to circumvent the conclusion that dolphins are individually aware of themselves, but these soon start sounding pretty strained.

The open question is the necessary threshold of proof and the unspoken assumptions that may accompany the adaptation of a primate mirror-mark test to a cetacean. Perhaps the real "flipper effect" is subtler: our own current inability to quantify meaningfully an advanced alien intelligence in any but primate terms.

DONALD J. WHITE [co-author of "Ring Bubbles of Dolphins"; SCIENTIFIC AMERICAN, August 1996]
Director, Earthtrust.org

WHERE THE BIOFILMS ARE

As promising as furanones appear to be for defending against the early proliferation of biofilms ["Battling Biofilms," by J. W. Costerton and Philip S. Stewart], remember that biofilms have millions of years' pedigree in a saline environment. It is possible that the use of furanones in solving human problems could trigger the development of bacterial resistance in nonsaline applications. Fish and slugs remain bacteria-free, yet if their skin is abraded, they can develop infections and die. Perhaps the antibiofilm mechanism is more prevalent than we suspect.

OLAF NIELSEN
Portland, Ore.

OIL DRILLING VS. CONSERVATION, CONTINUED

With two senators and a congressman sounding off in favor of drilling for oil in the Arctic National Wildlife Refuge [Letters to the Editors, September], I'd like to point out that the senators' numbers will be off unless we cut the growth in oil consumption, because in 10 years, three billion or six billion or 16 billion barrels just won't be all that much. We use seven billion barrels a year now. This is a pitiful showing for a nation that once prided itself on rising to challenges. We can already cut our energy needs by half—three quarters in the electric sector—using nothing except technology that exists today and saves more money than it costs. Even the Department of Energy's conservative "Clean Energy Future" report identifies the cost-effective potential as one third of today's consumption and shows that controlling climate change costs less than not controlling it. If we can eliminate only one third of consumption for less money than it costs, that's still enough to justify a massive change in emphasis and funding priorities on the part of the federal government. All we need are public officials who believe that the U.S. still has what it takes.

Incidentally, your readers might like to know that one reason the caribou are increasing near the Trans Alaska Pipeline is because pipeline workers were encouraged to kill all the wolves in the area during their off-hour hunting.

NED FORD
Chair, Energy Technical Advisory Committee, Sierra Club
Cincinnati

NATIVE MYTH

Robert Redford writes [Letters to the Editors, September] that the native people of Alaska left the land as they found it. Actually, indigenous Americans made vast, permanent changes in the environment to the extent that their technology permitted. Throughout the New World, for example, the Indians deliberately set uncontrollable fires to encourage particular plants to grow, which in turn increased the numbers of game animals that they killed for food. Through overhunting, they also caused the extinction of huge herds of Pleistocene mammals that roamed the New World before their arrival. In Mesoamerica the Mayans cut down great jungle areas to build their stone temples and cities.

Virtually all species seek to change to their benefit the world they live in—it is a grand axiom of nature. A stand of oil rigs in Alaska is, in principle, not different from the termite mounds littering the savannas of Africa.

NORMAN FINE
Sewell, N.J.

CLARIFICATION The micro fuel cell shown in the photograph in "Fuel Cell Phones," by Steven Ashley [News Scan, July], is manufactured by the Fraunhofer Institute for Solar Energy Systems in Freiburg, Germany.

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50, 100 & 150 Years Ago

Uneven Progress ▪ Dubious Milestones ▪ Disputed Origins

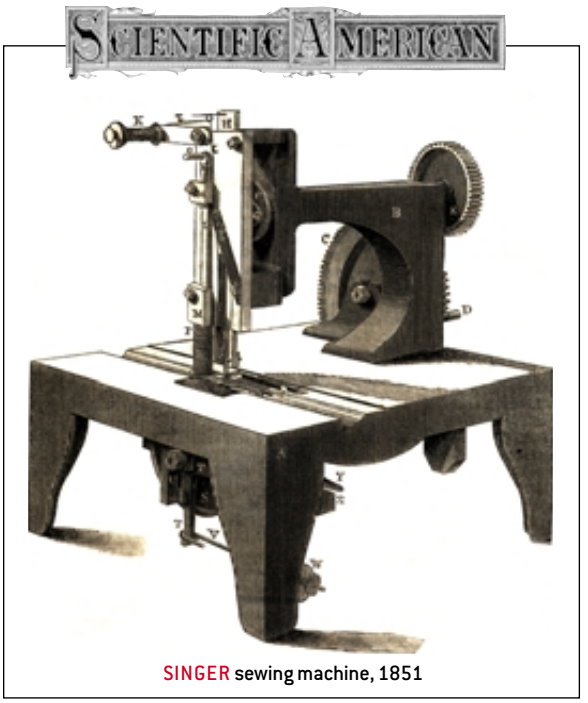
NOVEMBER 1951

POOR BABY, SICK BABY—"In Great Britain a Child Health Survey found that high infant mortality was traceable to three chief afflictions of the poor: higher rates of premature birth, pneumonia and gastroenteritis. Though all socioeconomic groups have shown appreciable decreases in infant mortality since 1939, the improvement has been greatest in the wealthier categories, so that the medical advances of the last decade have actually widened the gap. Among all groups the greatest cause of death in the first month is premature birth. It is suggested that this excess is due to early childbearing, closely spaced births, poor prenatal care and excessive work during the last months of pregnancy."

PURPLE BACTERIA—"By studying the responses of single cells to very simple stimuli we may elucidate the behavior of more complex organisms. An effective response to light is exhibited by the purple bacterium *Rhodospirillum*. This corkscrew-shaped creature can swim forward and backward with equal ease. When it encounters a decrease in illumination, it simply reverses its direction of swimming. If all excitable living systems have a common physical mechanism for irritability (i.e., response to a change in environment), then the essential relations between stimulus and response should be the same in every case. Thus it should be of great interest to see whether the responses in purple bacteria are quantitatively similar to those in nerve fibers.—Roderick K. Clayton and Max Delbrück"

NOVEMBER 1901

AVIATION MILESTONE, MAYBE—"The committee in charge of the Deutsch prize decided on November 4 that M. Alberto Santos-Dumont was entitled to it by his achievement of October 19, a flight around the Eiffel Tower, in his dirigible. While M. Santos-Dumont has performed a notable feat, it does not necessarily follow that he has accomplished anything of very great value. He has demonstrated the fact that with a very costly and delicate apparatus, a skillful aeronaut may, under favorable conditions, arise from a given point, make a circle and return, without being killed. The event, pleasant as it is, does not mark a step in the direction of the practical realization of aerial navigation. It is probable that the solution of aerial flight will never be reached in a way which will have any commercial value until the dirigible balloon idea is abandoned and that of a mechanism built on a strictly mechanical basis is substituted."



SINGER sewing machine, 1851

THE FIRST NAUTICAL PERISCOPE?—"An Italian engineer, Signor Triulzi, has devised a special instrument, the 'cleptoscope,' whereby it is possible for the crew of a submarine boat to ascertain what is progressing on the surface while submerged. It comprises a tube fitted with crystal prisms. Experiments were carried out on board the submarine *Il Delphino* in the presence of the Italian Minister of the Marine. Photographs of objects on the surface were successfully obtained." [*Editors' note: Simon Lake is usually credited with the invention of the periscope, in 1902.*]

NOVEMBER 1851

SINGER'S SEWING MACHINE—"The accompanying engraving represents a perspective view of Isaac M. Singer's Sewing Machine, which was patented on the 12th of last August. The way in which the stitch is performed is by two threads, one supplied with a shuttle, the other by the needle. Without two threads, no good stitch has yet been made by any sewing machine. This machine does good work." [*Editors' note: By 1913 annual sales of Singer sewing machines had reached 2.5 million.*]

COLT REVOLVERS—"Letter to the Editor: 'Sir—A great deal has been said lately respecting the claim of Mr. Colt to the invention of the revolving pistol; it will, perhaps, throw a light on the subject when we state that in the year 1822, we made the barrels of 200 muskets and 200 pistols, upon precisely the same principle as those exhibited by Mr. Colt, for a Gentleman named Collier. —John Evans & Son, London.' The Editor's reply: 'It is not uncommon to claim many new American inventions to be of English Origin. We cannot believe in the above; Mr. Colt is no doubt an original inventor.'" [*Editors' note: It is probable that Samuel Colt actually saw and copied some features of Elisha Collier's 1818 pattern flintlock revolver for his 1836 pistol.*]

FROM *SCIENTIFIC AMERICAN*

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9/11/01

Facing a New Menace

THE TERRORIST ATTACKS PROMPT A RETHINKING OF AIRPORT SECURITY **BY GARY STIX AND PHILIP YAM**

Like generals, technologists who implement new security measures are often fighting the last war. The bombing of Pan Am flight 103 by plastic explosives in 1988—and the fear that TWA flight 800 had been downed by a bomb in 1996—spurred investments in research and actual purchasing of new detection equipment. No one was thinking at the time about box cutters. For better or worse, however, experts agree that future attacks on the U.S. are still likely to involve guns and bombs and that the country needs to fortify itself against these weapons, as well as simple blades.

Screening technology has improved from its intensive development phase a decade ago. The Federal Aviation Administration has thus far installed some 140 high-tech scanners at 46 airports that use computed tomography to examine selected luggage for weapons and explosives. Similarly, nearly 800 trace detectors that "sniff" chemical residue of explosives on baggage or clothing have been deployed at 172 airports.

But there is still no single, compact, relatively inexpensive machine that can detect all types of explosives and weapons at high speed with few false alarms. The CT machines, for instance, do not supply proof positive of the presence of an explosive. Objects of like densities can set off an alarm. "I always thought that Christmas cakes had the density of granite," says senior research scientist Richard C. Lanza of the Massachusetts Institute of Technology, who has served on airport-security review panels. "They don't. They have the density of explosives." Moreover, a full deployment of CT machines and sniffers in the 450

GREG MARTIN *Corbis Sygma*

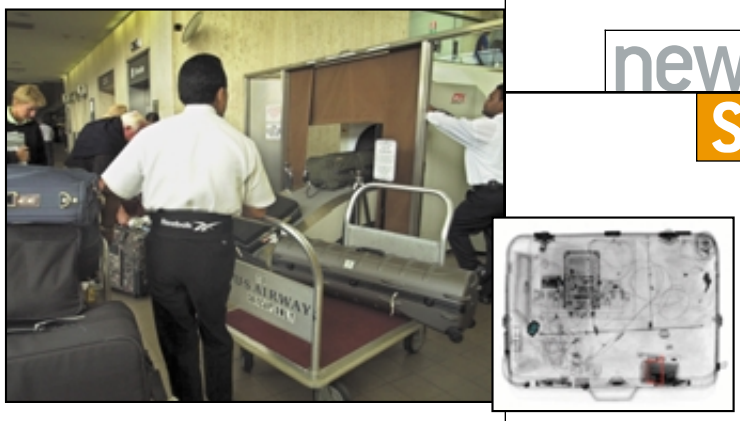


THE EVIL THAT MEN DO: On the morning of September 11, the world became a worse place to live.

SECURITY VS. LIBERTY

Deborah Hurley, director of the Harvard Information Infrastructure Project, says that widespread deployment of face-recognition technology and other biometric systems would essentially turn everyone into a suspect. "Before we run to solutions with strong deleterious side effects, we should examine bread-and-butter security measures, such as better-trained security personnel," Hurley says. "To move now to constrain civil liberties is to play into the terrorists' hands."

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SCANNERS using principles of computed tomography can better spot dangers in luggage. A test reveals a can bomb (*red outline in inset*).

NICK UT *AP Photo*; INVISION *AP Photo* (*inset*)

or so airports at which the FAA oversees security is not scheduled for years to come.

The success of the technology also depends on how well security agents use the devices. The human part of the equation has long been a problem. In 1978 the FAA found that screeners (who in 2000 checked some two million passengers and their carry-ons a day) let by 13 percent of deadly objects. More recent tests revealed even poorer performance, especially under conditions approximating a real checkpoint breach by a terrorist. Wages sometimes below fast-food work, job turnover averaging 126 percent a year and poor benefits contribute to the dismal results, according to the General Accounting Office. Pay is higher and turnover lower in other countries, such as Canada, France and the U.K.

Efforts to improve screener performance have lagged. According to FAA spokesperson Paul Takemoto, the agency has installed 600 threat-image projection (TIP) systems designed to superimpose images of suspicious objects on bags going through x-ray machines. The idea is to measure how well screeners do—and replace those who fail to spot threats. But so far the devices have been used only as training tools, not as performance gauges. The FAA hopes to have TIP systems in all airports within three years. Much more may be forthcoming from regulators. Agency spokesperson Rebecca Trexler adds that the current technology upgrade program could be overhauled because of the attacks. "All kinds of things are being considered now," she says.

In 1997 the U.S. tried to address some of the screeners' problems by expanding the use of computer-assisted passenger screening, or CAPS. The system uses preprogrammed criteria and "data from computer reservation systems to select bags" and culls a few randomly, Takemoto says. Selected bags are scanned with explosive-detection devices or loaded only if they can be linked to boarded passengers. Citing security reasons, he would not divulge the criteria used for CAPS (critics liken it to profiling, targeting especially those of Middle Eastern descent) or whether it has actually ever been used to derail a threat.

Baggage screening presumably would not stop a terrorist toting just a small knife, so there needs to be some emphasis on passenger screening. Israel's El Al Airlines, whose personnel extensively question passengers, has long been lauded for its security, but skeptics note that the model would not work given the vastly greater number of passengers in the U.S.

Simply establishing the identity of a passenger may thwart possible terrorism. For instance, Americans could be required to carry "smart" cards that could store a wealth of personal information. Cards might be coupled with biometrics—the scanning of a fingerprint, eye, voice or face to confirm identity. "Biometrics would be an instantaneous background check to determine if a passenger is a known terrorist or criminal," says Joseph J. Atick, chief executive officer of Visionics, a leading company in face recognition.

These systems have progressed enough that they can match a face in a crowd to a mug shot stored in a database. Atick says that hundreds of cameras can be connected to a system that compares an image against a million faces in a database every second. The system may be further refined so that it could detect someone on the street with a slow, heavy gait who might be carrying a bomb. It might also be used in conjunction with so-called data-mining software: a face that appears frequently in photographs beside Osama bin Laden's might be flagged. Identity screening might have caught some of the September 11 terrorists—but not all, as many were apparently unknown to U.S. authorities.

No technology or procedure will guarantee absolute safety. And an inevitable cost of stepped-up security will be a loss of some personal liberty. To those affected by the thousands of sons and daughters, mothers and fathers who perished on that horrifying day, that appears to be a price worth bearing.

RECIPE FOR THE UNSPEAKABLE

The attack on the World Trade Center towers unleashed nearly 1,700 tons' worth of TNT.

Average height of towers: 1,365 feet

Total weight: 1.25 million tons

Collapse energy: 2×10^{12} joules

Equivalence to TNT: 500 tons

Energy in one gallon of jet fuel: 135,000 btu

Maximum fuel capacity of a Boeing 767: 23,980 gallons

Approximate fuel detonated at impact: 3,000 gallons

Explosive energy, both planes: 9×10^{11} joules

Equivalence to TNT: 180 tons

Burning energy from remaining fuel: 5×10^{12} joules

Equivalence to TNT: 990 tons

Maximum takeoff weight of a Boeing 767: 412,000 pounds

Typical cruising speed: 530 mph

Kinetic energy, both planes: 9×10^{9} joules

Equivalence to TNT: 2 tons

Energy released (tons of TNT equivalent) by:

- **Tomahawk cruise missile:** 0.5
- **U.S. tactical nuclear warhead:** 300 to 200,000
- **Typical tornado:** 5,100
- **Hiroshima bomb:** 20,000

Calculations by David Appell

SOURCES: Skyscrapers.com; U.S. Geological Survey; U.S. Department of Energy; Boeing Company; Chevron Corporation; Grolier's Encyclopedia; U.S. Navy; Mark A. Horrell, Illinois Math and Science Academy

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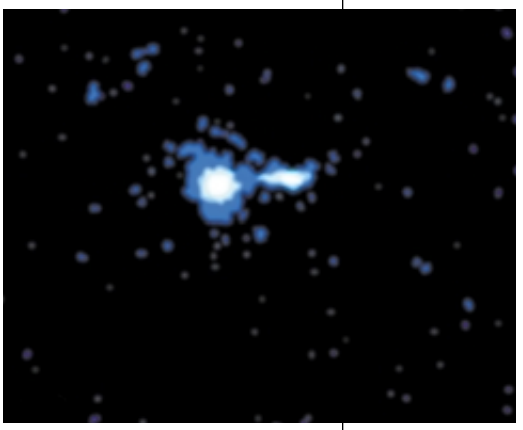
PHYSICS

Plus Ça Change

HAS A FUNDAMENTAL CONSTANT VARIED OVER THE AEONS?

BY GRAHAM P. COLLINS

If the result holds up, it will be one of the biggest discoveries in decades: billions of years ago the fundamental constant of nature that governs electromagnetism was slightly weaker than it is today. That would seem to fly in the face of one of the most cherished principles in all of science, namely that the laws governing the universe are the same everywhere and at all times. The evidence comes from studies of light from distant quasars carried out by an international group led by John K. Webb of the University of New South Wales in Australia beginning four years ago. The results have remained consistent even as the group has gathered more data and refined its methods of analysis.



ANCIENT LIGHT from quasars may harbor clues of altered physics.

Still, most astrophysicists remain skeptical. "My gut feeling is that some other explanation will be discovered for this observation," says Robert J. Scherrer of Ohio State University. "Of course, I'd love to be proved wrong; that would be very exciting."

Webb and his co-workers are also cautious. "Three independent samples of data, including 140 quasar absorption systems, give the same [amount of] variation" in the constant, explains theorist Victor V. Flambaum of the New South Wales group. "However, as with any first observation, there is room for doubts. Serious conclusions should be made later, after independent checks of our current results."

The constant in question is the fine structure constant, or alpha, for the Greek letter used by physicists to represent it in equations. The data indicate that between eight billion and 11 billion years ago, alpha was weaker by about one part in 100,000. Among other effects, electrons in atoms would have been slightly more loosely bound to nuclei than they are today, increasing the characteristic wavelengths of light emitted and absorbed by atoms. Astronomers can study such ancient light by looking at distant quasars. In particular, they focus on secondary effects that shift individual wavelengths of an atom by slightly different amounts; very precise measurements of the separation between wavelengths provide a measure of alpha's change.

Astronomers have been conducting such studies since the mid-1960s and have seen no evidence of a change in alpha to the precision achieved. Webb and his co-workers, however, developed a new technique of looking at wavelengths from many chemical elements at once to improve the accuracy. Extracting the tiny change in alpha from that data is a complicated process, combining information from laboratory studies and intricate computer modeling of atomic quantum states. Many spurious phenomena and measurement errors could mimic the wavelength shifts. Webb and his colleagues believe they have verified that none of these effects could be producing their results, but other researchers are unconvinced.

The question can best be resolved by further experimental work using different methods, but few alternatives are known. Christopher L. Carilli of the National Radio Astronomy Observatory in Socorro, N.M., and his co-workers have studied microwave absorption by hydrogen, but they have done so only for redshifts corresponding to times more recent than six billion years ago. Their data and Webb's agree that no detectable change in alpha has occurred over that interval. Carilli hopes to find suitable hydrogen clouds at large redshifts for a direct comparison at earlier times. "A major technical advance," he says, "is the new Green Bank Telescope in West Virginia," which is the largest steerable radio telescope in the world. It began operations in August.

Studies of irregularities in the cosmic microwave background correspond to the time a mere 300,000 years after the big bang, providing a measure of alpha almost 14 billion years ago. Using the most recent data, Pedro P. Avelino of the University of Porto in Portugal and his colleagues have found no evidence of a change in alpha, to an accuracy of about 10 percent. Data in the next few years from the recently launched MAP satellite may

NASA/CXC/SAO

CONSTANT STRUGGLE

Several methods have sought to determine the stability of alpha, a fundamental constant:

- **The abundance of light elements such as helium and lithium in the universe suggests alpha was unchanged to within 2 percent a few minutes after the big bang, when such elements formed.**
- **Atomic clocks in 1994 showed that alpha was constant to 1.4 parts in 100 trillion over 140 days, which extrapolates to four parts in 100,000 over a billion years. An "atomic fountain" experiment has improved the precision by a factor of five.**
- **In Oklo, Gabon, 1.8 billion years ago, a natural nuclear reactor formed in a deposit of uranium. The isotopes remaining imply that alpha was the same then as it is today to within a few parts in 10 million—about 100 times more precise than current astrophysical measurements.**

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tighten the limit to as little as 0.1 percent.

One is left with a puzzle of no discernible variation in the most recent epoch, none in the earliest (when the largest change might be expected), but the tiny variation of one in 100,000 between eight billion and 11 billion years ago. "Even if their result doesn't hold up," Carilli says, "they certainly have spurred interest in this field and have motivated many experimentalists to expand their efforts."

ASTRONOMY

Earth-Shattering Theory

FINALLY, THE DETAILS FOR FORMING THE MOON WORK OUT

BY GEORGE MUSSER

If you ever find yourself at a cocktail party of astrophysicists and don't know what to say, try this: "But what about the angular momentum?" No matter what the topic of conversation, you'll be guaranteed to sound erudite. Nearly every field of astronomy, from galaxy formation to star formation, has an "angular momentum problem." Nothing in the cosmos ever seems to spin or orbit at the rate it should.

The moon is no exception. It is the flywheel to end all flywheels; if its orbital angular momentum were transferred to Earth's axial rotation, our planet would come close to spinning apart. No other planetary sidekick wields such power, except for Pluto's cryptomoon, Charon. The moon's prodigious angular momentum is one reason that planetary scientists believe that it formed when another planet—no piddling asteroid but an entire Mars-size world—struck the proto-Earth.

Unfortunately, researchers have had trouble getting the giant-impact model to work without the contrivances that scuttled earlier theories. "Putting enough material into orbit to form the moon seemed to require a rather narrow set of impact conditions," says Robin M. Canup of the Southwest Research Institute in Boulder, Colo. But a new study by her and Erik Asphaug of the University of California at Santa Cruz may have broken the logjam.

Although the giant-impact model became dominant in the mid-1980s, fleshing it out has been a gradual process. Simulations have attempted to reconcile the angular momentum with three other basic facts: Earth's mass, the moon's mass and the moon's iron content. These four quantities depend on three basic attributes of the collision: the impactor's mass, the proto-Earth's mass and the impact angle.

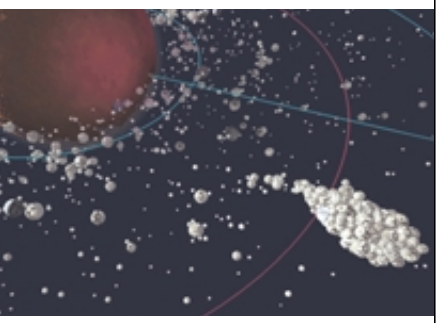
Four facts and three parameters is a recipe for contradiction. To explain the moon's low iron content, you need to avoid a grazing collision (corresponding to a large impact angle), lest too much of the impactor's iron spill into orbit. Then, to explain the angular momentum, you need to compensate for the smallish angle with a hefty impactor. Then, to explain the moon's mass, you need to adjust the proto-Earth's mass. In the end, you might find that the total mass is incorrect.

In 1997 Alastair G. W. Cameron, one of the fathers of the giant-impact theory, now at the University of Arizona, arrived at a total mass that was a third too low. He suggested that subsequent asteroid impacts made up the difference. But few liked the idea, as the asteroids would have added extra iron.

Canup and Asphaug argue that the fault lies not in the stars but in our simulations. The calculations rely on a technique known as smoothed-particle hydrodynamics, which subdivides the bodies and applies the laws of physics to each piece. Early runs tracked 3,000 pieces—leaving the iron core of the moon to be represented by just a single piece. Even the slightest computational imprecision could vastly overstate the iron content, in which case the computer compensated by reducing the impact angle. The result was a bias toward heavy impactors and light proto-Earths. Because Canup and Asphaug use 30,000 particles, they get by with a much smaller impactor. Everything—mass, iron, momentum—clicks into place.

Considering all the twists and turns in lunar science, nobody claims that the models are complete just yet. Cameron says Canup and Asphaug's model doesn't track events for a long enough time, and moon modeler Shigeru Ida of the Tokyo Institute of Technology says that further increases in resolution could cause more upheaval. Still, it may not be long before you'll need a different cocktail-party question.

WITHIN THE DEBRIS DISK thrown up by a giant impact, the moon began to coalesce after a few days.



EIICHIRO KOKUBO *National Astronomical Observatory Of Japan* AND HITOSHI MIURA *Musashino Art University*

SOLVING MYSTERIES: MOON FORMATION

- **Why didn't debris from the impact just fall back to Earth? To reach orbit, a rocket has to fire its engines at least twice: first to lift off, then to circularize its trajectory. Rockets that forget the second burn are ballistic missiles. Researchers think that the lopsided gravity of the mutilated Earth and pressure gradients in the vaporized debris did the trick.**
- **Why is the moon's orbit tilted? The impact debris should have settled into a Saturn-like disk aligned with Earth's equator. Last year researchers argued that gravitational interactions with residual debris quickly wrenched the nascent moon out of that plane; much later on, the sun's gravity reoriented the orbit yet again.**
- **Why is there only one moon? A sufficiently large debris disk could have given birth to a family of moons, rather like Jupiter's. But recent work found that the siblings would have merged or been ejected. Jupiter's moons escaped that fate because the tidal torques that cause orbits to move around are weaker in the Jovian system.**

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No Power to the People

DOES LOW-POWER FM RADIO CAUSE UNACCEPTABLE INTERFERENCE? BY MARIAMA ORANGE



BIG RADIO sweats the small stuff.

In January 2000 the Federal Communications Commission, under the administration of then chairman William Kennard, authorized the creation of an exclusively noncommercial low-power FM (LPFM) radio service. By squeezing between existing stations in the FM band, low-power stations would provide local access and diversity to airwaves now dominated by media conglomerates.

That vision, though, has been clouded by LPFM opponents—largely those who already have a license to broadcast. They argue that the new stations would make the already snug FM band too close for comfort, producing unacceptable levels of interference. Their claims have already led the FCC to tighten the specifications on its original LPFM proposal and pushed Congress to pass legislation that severely curtails the number of eligible LPFM slots by 75 to 80 percent. Yet Congress may be reacting more to political pressure than technical data, which suggest that whatever interference LPFM stations generate will be too low to matter.

Today's FM stations operate in 200-kilohertz-wide channels, transmitting at center frequencies that range from 88.1 to 107.9 megahertz. The closer in frequency that two stations broadcast, the farther away they must be from each other geographically to prevent interference. The FCC prescribes minimum-distance separation rules for stations whose center frequencies are three channels (600 kilohertz) apart or fewer.

Because LPFM stations transmit only at 10 or 100 watts, reaching out no more than 3.5 miles, the FCC originally decided to waive the 600-kilohertz separation reqirements for them. (Full-power stations pump out 6,000 to 100,000 watts, covering an area in an 18- to 60-mile radius.) Congress's action, however, effectively enforces the 600-kilohertz separation requirements, leaving no spectrum for a significant number of the originally planned LPFM stations. That's exactly the point, according to LPFM opponents, which include the National Association of Broadcasters (NAB), National Public Radio and the Consumer Electronics Association. "It is impossible to shoehorn the number of stations [the FCC had wanted] without significant interference for listeners," states Dennis Wharton, NAB senior vice president of communications.

But three-channel-wide protection isn't necessary for LPFM, argue advocates that include the Media Access Project (MAP), the National Lawyers Guild's Committee for Democratic Communications and the Prometheus Radio Project. Technical studies conducted by the FCC's own engineers conclude that relaxing the 600-kilohertz rule for LPFM would not result in much new interference for existing stations. In addition, one of the major purposes of authorizing LPFM stations was to fit them into buffer zones too small to accommodate full-power stations, thereby maximizing spectrum efficiency.

The LPFM debate has prompted key questions about how to determine what levels of interference actually cause problems. Wharton disagrees with those who describe LPFM as producing "acceptable levels of interference," dismissing their conclusion for inappropriately using a creative phrase. Similarly, LPFM proponents have discounted an NAB technical study submitted to the FCC for inappropriately using creative testing procedures. The NAB study found that receivers would not be able to stand up to interference produced by relaxing the 600-kilohertz rule for LPFM; however, MAP counters, the same study used an arbitrary performance threshold so extraordinarily high that most of the receivers failed to measure up even when there was no interference present.

In February, Senator John McCain of Arizona introduced the Low Power Radio Act of 2001, which would essentially reverse Congress's decision to curtail LPFM. That bill still awaits action. Meanwhile, starting this past April, the FCC has slowly begun doling out the first LPFM construction permits, barely squeezing out a taste of the airwaves to appease the flood of communities starving for a voice.

Mariama Orange is an electrical engineer from Howard University.

SEPARATION ANXIETY

The mandatory spacing scheme for FM radio was adopted in 1963, when radios were primarily analog and tuned by turning a knob. "The spacing requirements never changed" to reflect current technology, explains Bruce A. Franca, acting chief of the FCC's Office of Engineering and Technology. An August 1999 study conducted by Wireless Valley Communications, an engineering firm based in Blacksburg, Va., found that modern FM receivers, which use digital frequency synthesis and phase-lock loop detection, can tolerate much closer adjacent channel spacings than FCC rules allow.

RUSSELL ILLIG *PhotoDisc*

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Acronym Acrimony

DO WHIMSICAL NAMES ENCOURAGE SALES OVER SCIENCE? BY BRENDA GOODMAN

What's in a name, the Bard asked. We thought about titling this story "SMART" (See My Article? Read This!), "WISE" (Writing Inside Smartest Ever) or "FUNNY" (Fine Use of Nouns and No Yawns). The struggle to strike a balance between an eye-catching, memorable name and a suggestive sales pitch is becoming a topic of debate in medical research, too. Scientists and ethicists are raising eyebrows over what they say is a shift in the way sobriquets are used for clinical trials, wondering if a few letters may end up spelling big money for pharmaceutical companies but trouble for good science.

Steve R. Cummings, for example, says that he is still less than satisfied with MORE. An epidemiologist at the University of California at San Francisco, Cummings was asked to be a principal investigator on a trial sponsored by the drugmaker Eli Lilly. The test would pit the company's new designer estrogen, raloxifene, against traditional compounds used in hormone replacement therapy. The goal was to see which offered women the greatest number of benefits, among them stronger bones and the prevention of mental decline.

But the company already seemed to know the answer when it dubbed the trial Multiple Outcomes of Raloxifene Evaluation, or MORE. "If you want people to remember in the long run that this does 'more' than estrogen therapy, or it's bigger and better, you give the trial a name you can refer to over and over again in product literature" or in presentations at scientific meetings, Cummings remarks.

And at least in this case, a good name may have paid off handsomely. The MORE trial essentially showed that raloxifene offered no additional benefits over traditional therapies—and in some instances, it exacerbated medical conditions. Still, following the trial's outcome, first-quarter sales of raloxifene rose 47 percent. That's a jump in sales of $48 million.

Medical ethicist Rebecca Dresser of Washington University wonders about the effects some acronyms could have on patients. Dresser says acronyms such as CURE, HOPE and MIRACLE could promote "therapeutic misconception," a mistaken belief that a study intervention is equivalent to proven therapy. "An acronym like MIRACLE for a trial conducted with an extremely vulnerable population, like heart failure patients, plants the idea that the research intervention is better than existing therapy," she says. "Of course, if that were established, the trial would be unnecessary." Angela Bowen, president of the Western Institutional Review Board, is also worried about the increasing practice of giving naming rights to spin doctors instead of medical doctors. She says that before her group has given some trials the thumbs up, it has had to ask drug companies to remove acronyms from informational materials for patients. "They promised more than can be delivered," she states.

And then there's the issue of whether suggestive names can bias results. "It would be very interesting to sign two groups of patients up for the same protocol but give it different names and see which group does better," remarks Michael Berkwits, assistant professor of medicine at the University of Pennsylvania.

But Berkwits is also quick to say that all acronyms for clinical trials needn't be dumped. Indeed, that would be difficult to do—over the past 15 years, researchers have displayed nothing but a burgeoning affection for acronyms. Names are ways to unite geographically and institutionally distant investigators under a common identity. And a positive acronym can help boost research enrollment. "Nobody's going to sign up for a trial named DEATH," he quips.

Au contraire. Just ask the teams who dreamed up Dying Experience At Dartmouth, or Dying Experience At The Hitchcock.

Brenda Goodman is a freelance science writer in Orlando, Fla.

BETH PHILLIPS

news SCAN

ON TRIAL: Whimsy leads to worry.



LIGHT ON THE LINGO

Coming up with acronyms is a way for clinical investigators to have a little fun with an otherwise dry task. Cardiology trials alone generate a multitude of fanciful names. Pet projects having nothing to do with animals include CHAMP, CAT and WOOFS. There are trials named by people without enough on their plates: TOAST, FIG, DISH, BIG MAC and KFC. And there are names from wordsmiths to whom the muse was not kind: the mangled HELVETICA, for Hirudin in a European restenosis prevention triaL Versus heparin Treatment in PTCA (angioplasty) patients. Then there are the subtle pleas for recreation: STARS and its spin-off CRUISE, wistfully referred to as CRUISE under the STARS.

The synaptically overloaded can see 1,500 other monikers at www.pulseonline.org/prof_ed/trials/acronyms.html

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AEROSPACE

Taking the Plunge

TWO DAREDEVILS PLAN TO SKYDIVE FROM THE STRATOSPHERE **BY CHRISTINE KENNEALLY**

In two separate endeavors next year, Rodd Millner, an Australian ex-commando, and Cheryl Stearns, a US Airways pilot and skydiving world-record holder, plan to ride giant balloons up to 130,000 feet (about 25 miles) and then jump out. Both claim that free-falling through the ozone layer will push back the boundaries of science. Undoubtedly, their efforts will generate data about stresses the human body can—or cannot—endure. But then again, so does MTV's *Jackass*.

Science or not, if they succeed, Millner and Stearns will break multiple records, including the highest manned balloon flight (currently at 113,740 feet) and the highest free fall (102,800 feet), set in 1960 when U.S. Air Force Captain Joe Kittinger leaped from a balloon. They also plan to be the first people to break the sound barrier without a vehicle. (There is still controversy surrounding whether Kittinger actually broke the sound barrier, but at the time even the jumper himself said he didn't.) They will slow down as they descend into the thickening atmosphere, reaching a terminal velocity (the speed at which the upward force of air resistance prevents them from accelerating any more) of approximately 120 miles per hour.

Taking the two-and-a-half-hour trip to the top of the stratosphere is challenging enough: research balloons don't routinely carry much weight when they enter such rarefied territory. To cope with the payload, Millner's and Stearns's balloons will be massive. With a volume of at least 12 million cubic feet each, the balloons will be visible to the eye even at their highest altitude. And for the human body to survive the trip up as well as the six-minute plunge down, special pressurized suits with their own oxygen supplies will be needed. Both Millner's and Stearns's teams—Space Jump and Stratoquest, respectively—are keeping quiet on the details of the suits' construction, however. "It's a trade secret," says Per Lindstrand, a well-known balloon maker and sky diver in Oswestry, England, who will be modifying Stearns's suit. Lindstrand will admit only that its material will be similar to Vectran, a high-tech polyester used in aerospace applications, and to Kevlar, but without the material fatigue associated with those fabrics.

Things will get toasty on the way down, but a reentry burn-up isn't in store, because air friction presents a problem only beyond Mach 2. Although the dynamic duo should pick up enough speed so that high-altitude winds will not be a problem, they are not likely to land very close to their targets. Stearns, for one, hopes to get within 100 miles of hers.

Modern wing-shaped parachutes can put people down at near zero speed and can even land unconscious people at a gentle seven miles per hour. "The way a chute inflates is never the same from one jump to the other," says Jean Potvin, a specialist in parachute physics at St. Louis University who has completed more than 2,000 jumps. The aerodynamics of the chute depends on how it is inflating, which in turn affects the aerodynamics, creating a complicated feedback mechanism.

So is it science? Potvin thinks so, albeit more in the spirit of Chuck Yeager than Jonas Salk. "If they can achieve free fall at supersonic speeds," he says, "that would definitely be a valid enterprise." The jumps may point the way to escape strategies for astronauts—although whether they are needed is up for debate. Astronauts have very little time to bail out of a launched spacecraft, and while it's true that shuttle astronauts wear parachutes, "they are more a psychological device than a bailout device," Potvin says. Both teams are still searching for the funding required to ensure the success of the jumps. Millner hopes to bail out over central Australia's red desert in March; Stearns, over the southwestern U.S. in April.

Christine Kenneally is an Australian writer living in New York City.

HIGH-ALTITUDE SKYDIVING may take on a new meaning next year.



TIM HANRAHAN AND CARL CARPENTER

KEEPING CONTROL FROM 25 MILES UP

To skydive successfully from the top of the stratosphere, Rodd Millner and Cheryl Stearns will have to maintain control of their bodies during free fall. Because they will be carrying oxygen supplies and cameras, as well as wearing pressurized suits, they will be much heavier than usual. They will also be less flexible, which could interfere with proper body positioning and could lead to a spin, keeping the chutes from opening properly or causing the sky divers to lose control or to black out.

Jump height: 130,000 feet

Balloon ride time: 2.5 hours

Plunge time: 6 minutes

Maximum velocity: about 900 mph

Terminal velocity: 120 mph

Speed of sound above 36,000 feet: 660 mph

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Cleaner Living

A WELCOME DROP IN THE HAZARDS OF BEING AN AMERICAN TEEN **BY RODGER DOYLE**

Those who worry about adolescent decadence may find comfort in the 2001 edition of *America's Children,* an annual statistical report by a consortium of federal agencies. It shows that out of 17 prime indicators of adolescent well-being, seven improved since the last reporting years while none got worse. But as illustrated by the graphs, which display five of the most important indicators, the longer-range picture is mixed.

Substance abuse by the nation's 27 million teenagers appears to be inching down from its extraordinarily high levels of 20 years ago, but it is still excessive from a public health perspective. Of the three million high school seniors enrolled last year, 300,000 used an illegal drug other than marijuana in the month prior to being surveyed; 60,000 of these used cocaine. Almost a million were intoxicated at least once in the month in question; 50,000 got drunk every day. Cigarette smoking in this group is down from its high of 39 percent in 1976 to 31 percent in 2000, but 350,000 consumed half a pack or more every day. In the month before the survey, 100,000 used smokeless tobacco daily, which is causally related to oral and nasal cancer.

Since 1996 an increasing number of children younger than 18 have lived in areas that do not meet one or more of the Environmental Protection Agency's air-quality standards, a particular problem for those with asthma or other respiratory illnesses. According to the U.S. Department of Agriculture's "Healthy Eating Index," only 6 percent of those 13 to 18 years old had a "good diet" in 1996, whereas 20 percent had a "poor diet," one so unbalanced that it increases the risk of obesity and certain diseases. About a third of high school seniors do not have basic math and reading skills, and there are few signs that this is improving [see "Can't Read, Can't Count," By the Numbers, October].

Among the more positive developments is the decline in poverty among young people and the shrinking number of high school dropouts. In the 1990s fewer dropouts, combined with more job opportunities, resulted in diminishing numbers of idle teenagers, a trend that may have contributed to the recent fall in crimes involving young people. Another encouraging sign was a growing tendency for high school graduates to get a college degree: Among 25- to 29-year-olds, 33 percent had a college degree in 2000, compared with only 26 percent in 1980.

For more than a generation, the trend of adolescent girls to have children out of wedlock has been a leading indicator of social pathology, and so the modest decline evident in the latter half of the 1990s is good news. According to the National Center for Health Statistics, several developments account for this, including increased contraceptive use and, possibly, greater awareness among teenagers of the value of abstinence.

Rodger Doyle can be reached at rdoyle2@adelphia.net

news SCAN

NEED TO KNOW: YOUTH MOVEMENT

Seven of 17 indicators for teenagers' well-being show improvement. "Latest year" refers to the year in which the indicator was last measured: 1998, 1999 or 2000.

Improved Indicators

Previous year / Latest year

Percent in poverty 18 / 16

Percent with secure parental employment 77 / 79

Percent with health insurance 85 / 86

Deaths per 100,000, ages 15 to 19 75 / 71

Births per 1,000, females ages 15 to 17 30 / 29

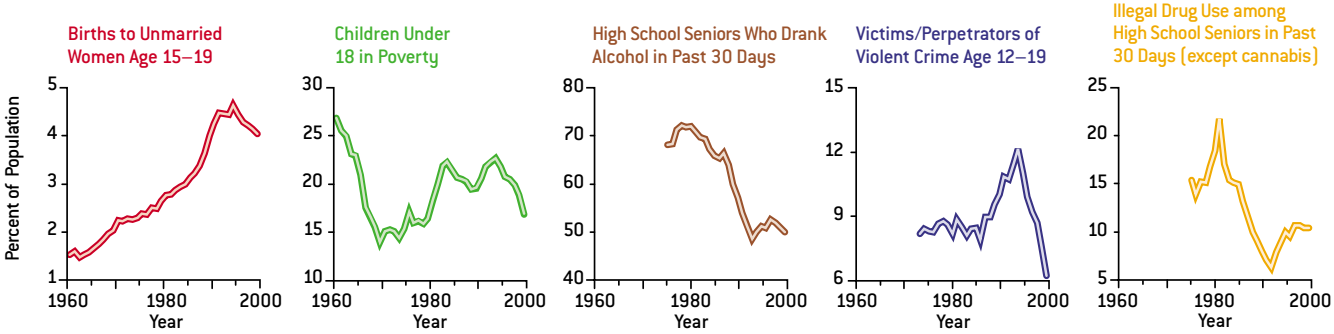
Percent of 12th graders who smoked cigarettes in previous month 23 / 21

Percent of seniors graduating high school 85 / 86

No Significant Change

Housing
General health
Activity limitation
Cigarette smoking
Alcohol use
Illegal drug use
Victim or perpetrator of serious violent crime
Math and reading achievement
No job, not in school
Ages 25 to 29 with bachelor's degree

SOURCES: America's Children: Key National Indicators of Well-Being 2001, *Federal Interagency Forum on Child and Family Statistics, Washington, D.C., July 2001; National Institute on Drug Abuse*



RODGER DOYLE

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ROBOTICS

Surgeons without Borders



LONG-DISTANCE OPERATOR: Doctors in New York City (*above*) operate on a woman in Strasbourg, France (*right*).

Telesurgery passed a significant milestone when doctors in New York City removed the gallbladder of a 68-year-old woman in Strasbourg, France. Using a system designed by Computer Motion in Goleta, Calif., Jacques Marescaux of France's Research Institute against Cancers of the Digestive Tract and his colleagues manipulated a control console that sent high-speed signals to robotic surgical instruments 7,000 kilometers away. The key to the success of the work—dubbed Operation Lindbergh—was a fiber-optic network that transmitted signals so quickly that doctors could see the movements of the instruments on a video screen 155 milliseconds after making them. Richard Satava, a professor of surgery at Yale University who helped to develop the system, says telesurgery may be particularly useful where doctors are few and transportation is difficult. "We know that it can work," he says. "Now we have to prove its cost-effectiveness." For safety's sake, Satava thinks the lag time should be no longer than 200 milliseconds, although the researchers, reporting in the September 27 *Nature*, think it can be pushed to 330 milliseconds, which would extend telesurgery's geographic reach.

—Mark Alpert



ASTRONOMY

New Kid on the Block

Seeing is believing: a group of astronomers from the European Southern Observatory have measured an asteroid and announced that it is the largest in the solar system. Calculations indicate that the icy rock, called 2001 KX76, could stretch 1,200 kilometers across, which would unseat the 200-year-old record held by the 950-kilometer-long Ceres, the first asteroid ever discovered. Scientists used a new virtual telescope called Astrovirtel, which relied on software to scan old photographs for images of the asteroid. Then they used that information, along with recent images from a conventional telescope, to calculate its orbit around the sun. Combining this measurement with the amount of sunlight reflected from the asteroid's surface provided an estimate of its size. The object's orbit lies just beyond that of Pluto, and it is even larger than Pluto's moon, Charon.

—Alison McCook



BIGGEST ASTEROID lies beyond Pluto.

FRANCE TELECOM/IRCAD (*top*); EUROPEAN SOUTHERN OBSERVATORY (*bottom*); ILLUSTRATION BY MATT COLLINS

DATA POINTS: DRIVE TIME 2000

Average travel time to work in the U.S., in minutes: 24.3
In New York: 31.2
In North Dakota: 15.4

Number of Americans over age 16 who work: 127,437,000

Percent who get to work by:
- **Driving alone: 76.3**
- **Carpooling: 11.2**
- **Taking public transportation: 5.2**
- **Riding a motorcycle: 0.1**
- **Riding a bicycle: 0.4**
- **Walking: 2.7**
- **Staying home: 3.2**
- **Other: 0.9**



SOURCE: U.S. Census Bureau, 2000; New York Times. *Error range for all Americans who work is ±0.2 percent. Information on sampling and nonsampling error can be found at http://factfinder.census.gov/home/en/datanotes/exp_c2ss.html*

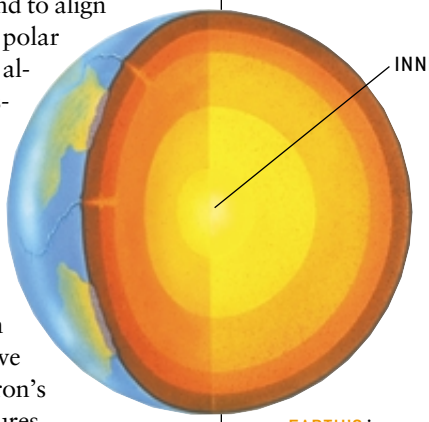
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GEOPHYSICS

Iron Deficiency

One of the most intriguing puzzles facing geologists is the fact that seismic waves from earthquakes move faster going between north and south than between east and west when traversing the earth's solid iron inner core. Researchers led by University of Michigan graduate student Gerd Steinle-Neumann may have a partial answer. Using supercomputer simulations, they conclude that iron's properties change at high temperatures and pressures. When subjected to an environment similar to that in the earth's core—with temperatures ranging from 6,740 to 12,140 degrees Fahrenheit—iron crystals become distorted. If planes of iron atoms in the earth's core tend to align themselves parallel to the polar axis, then the heat-induced alterations would allow seismic waves to travel faster in that direction but impede their progress along the equatorial plane. These results, which appear in the September 6 *Nature*, could influence the interpretation of seismic images, which have heretofore been based on iron's properties at low temperatures.

—Alison McCook



EARTH'S inner-core conditions modify the properties of iron.

CARDIOLOGY

Pressure Gauge

Taking your blood pressure while on the treadmill instead of at the doctor's office may be a more accurate way to determine the health of your heart. Using ultrasound images of patients' arms, researchers at the Johns Hopkins University Medical Institutions found that a high pulse pressure—the difference between the systolic (the higher number) and diastolic (the lower number)—during exercise is associated with the poor function of cells needed to expand blood vessels feeding the heart. Without adequate blood flow, the heart can become enlarged, which raises the risk of heart attack and stroke. The findings were presented at a September 14 meeting of the American Association of Cardiovascular and Pulmonary Rehabilitation.



OFF THE CUFF: A better time to take readings.

A high pulse pressure also results when aging arteries stiffen up. Another research group at Johns Hopkins reports in the September 25 *Circulation* that a drug called ALT-711 could soften rigid vessels. The drug breaks up chemical bonds that have formed between sugars and proteins, which over time lead to the loss of elasticity in arteries. With the sugars detached, the blood vessels' ability to stretch increased by about 14 percent.

—Diane Martindale

PHYSICS

Pushing the Fringe

It's often the little measurements in physics that have the biggest impact. So big things may soon come of an invention that gets around a fundamental limitation of interferometers. These devices use the bright and dark fringes produced when two laser beams interfere to measure distances as small as half the wavelength of the light. Yuri B. Ovchinnikov and Tilman Pfau of Stuttgart University in Germany recently found that a different approach can do even better. A single laser beam sent down a narrow channel between two mirrors, the scientists showed, propagates as several modes—like the harmonics of a plucked guitar string—that interfere with one another. That makes the fringes in the beam that emerges much finer than any seen before. Their first experiment measured distances one ninth the wavelength of the laser light, but theoretically the same technique could attain precision equal to the radius of a hydrogen atom. The work appears in the September 17 *Physical Review Letters*. *—W. Wayt Gibbs*

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BRIEF BITS

- Rather than just a bleaching of photopigments in the eye, visual afterimages can result from perceptual adaptations in the brain. /083101/1.html
- Two decades of satellite data show that, thanks to global warming, the Northern Hemisphere is greener: growing seasons are longer and plant life more lush. /090501/1.html
- Changes in glucose metabolism in the brain, detectable through PET scans, predict future age-related memory loss. /091101/3.html
- The essential oil in catnip drives away insects 10 times more effectively than DEET, a common pest repellent. No word on how to keep the cats away, though. /082801/2.html

DAVID HARDY *Photo Researchers, Inc.* (top); BRUCE AYRES *Stone* (bottom)

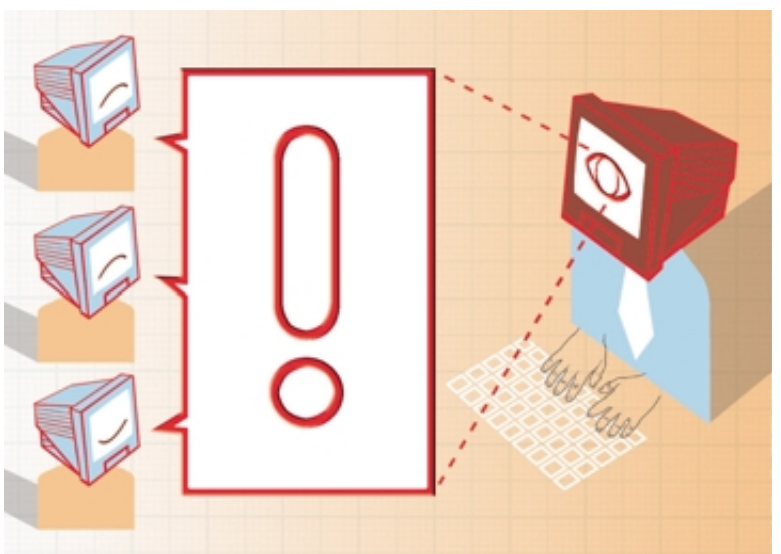
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Catching a Buzz

New Internet traffic watchers aim to elevate marketing to a science By JULIE WAKEFIELD

"Buzz" matters more and more in the business world. After all, the ability to be the first to latch onto a contagious idea—the kind capable of spreading faster than the "I Love You" virus on the Internet—could be worth millions in today's turbo-paced markets. Just getting a timely read on the cacophony of postings in chat rooms, newsgroups and electronic message boards could lock in a competitive advantage everywhere from Wall Street to the box office to the voting booth.

At least one new company intends to turn tracking Internet buzz into a science. By identifying opinion leaders on the Net, it claims, its software can in real time determine how people think and assess widespread shifts in consumer opinions—all without violating privacy. From the average technologist chasing early-stage funding from angel investors, a boast about such a feat would be cause for ridicule. But Opion CEO David Holtzman is not an average technologist. Even amid the dot-com meltdown, attracting start-up funding has not been a problem for the former U.S. Navy linguist, erstwhile IBM scientist and ex–chief technologist of Network Solutions, Inc. (NSI). He developed the shared registration system that NSI uses to record domain names and took the company from 750,000 registered names and $20 million in revenues at the start of 1997 to 10 million names and half a billion dollars in revenues in 2000.



JOHN McFAUL

Opion's headquarters in Herndon, Va., consists of a set of nondescript office suites that once housed former Nixon aide Charles Colson's Prison Fellowship Ministries. Whiteboards are everywhere. The open, blank spaces are just "what you need when you're innovating," says Holtzman, who helped to develop Minerva, a system for searching data repositories, and Cryptolope, the first commercial digital-rights management system, which was built for IBM.

During his days as the domain-name kingpin, Holtzman, who met his wife, Claudia, through an online dating service, realized that much of the revolution surrounding the Net was cultural. "It didn't appear to me to be about technology. For instance, the domain-name system is just a big linear database," he says. "There's really nothing on the Internet today that for all practical purposes wasn't around 20 years ago in some form or fashion." At about the same time, he also observed that "there were more and more things in this world that were subjective and just ignored." The business world and academia originally discounted much of what appeared in chat rooms and on bulletin boards.

But Holtzman remained convinced that the subjective parts of social interactions—be it a friend's recommendation of a movie or an urban legend you read about on the Internet—had become what increasingly mattered in formulating a calculus of cultural trends.

What is more, the lack of accountability in conventional demographic segmentation and advertising practices troubled him. "There's no way to do any predictive marketing whatsoever," he contends, despite the entrenchment of telephone polls, TV rating systems, focus groups and the like. In an increasingly global economy, "the idea that you can somehow segment the en-

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tire universe into these buckets by sex, age, ethnicity, income, et cetera, is crazy," he says.

Beginning in March 2000, using $250,000 of his fortune, Holtzman assembled a statistician, a social-networking theorist, an information-retrieval expert and others to explore how chat-room banter seemed to affect NSI's stock price. Several years and several patent applications later, his ad hoc team had devised software to measure what Holtzman calls "mindshare"—the buzz or subjective sentiments previously expressed anecdotally by marketers. Using proprietary mathematical modeling, Opion's core technology assigns a number to an individual as the software monitors message boards or people who sign up on the company's Web site. The model then ranks the person's influence in a given subject area. "It's not a matter of whether they are right or wrong but how much impact they have—how much other people believe them," Holtzman explains. Opion's system, which was formally launched in November 2000, can rate the relative influence of celebrity Wall Street pundits such as Mary Meeker and Henry Blodget, as well as those using pseudonyms on electronic bulletin boards devoted to stocks. Opion's software also allows individuals to register on the company's Web site: www.pseuds.org

For Opion to succeed, it must explain to the world at large what it intends to do to protect the privacy of the people it monitors. The company claims it has no intention of identifying the millions of Net users amassed in its database. It merely ensures that opinions related to a specific name on the Web reflect a consistent set of beliefs. Besides offering free pseudonyms to all comers, Opion designates those who post to its site by reputation scores alone, not names, although some doubts persist about whether simple programs could unravel these identities.

Financial-sector applications were the most obvious target. For a start, Opion's software can track a given stock or sector, gauge what noninstitutional investors are thinking, compare market activity with baseline data, and make predictions on the basis of past correlations between buzz and behavior. The modeling that Opion does for hedge funds and other financial institutions is similar to market predictors that use algorithms based on complexity theory. Opion's software uses a type of traffic analysis similar to that employed by the intelligence community: the number and order of citations for a person in a particular communication determines importance and thus rank. Opion also quantifies the person's degree of influence in a subject area: fixed income versus equity securities, for instance.

Initially, though, many leading Wall Street brokerage houses harbored some doubts that amateur postings on message boards could sway markets. One top firm was so skeptical, "they almost threw me out of the room," Holtzman recalls. Since then, Opion's buzz scores have been more than validated, he claims. New players such as Vancouver's MindfulEye have developed other types of engines that scour Net postings by using natural-language parsers and analyzing patterns of words to determine emerging trends.

Guesswork will be less a part of movie marketing if Holtzman gets his way. Opion is already building buzz trackers for executives at three major studios to help them better understand the relation between advertising, buzz and box-office receipts. Holtzman also envisions applications for pharmaceutical companies, consumer product manufacturers, multinationals and even politicians. By learning virtually instantaneously what influential Web posters are saying about a product, businesses can more effectively target marketing or damage-control campaigns. "There's never been a rational way of quantifying this stuff because there's never been enough data to do this before," he says. While opening a channel to more than 250 million people's opinions and interests worldwide, the Internet also offers an anonymous microphone to all, which marketers and pollsters should heed but also beware because of the potential for large-scale deception.

Software that monitors the Web will help movie studios trace the relation between advertising buzz and box-office receipts.

Holtzman is indeed wise to the dark side of the dot-com world. To ensure that his buzz trackers can't be fooled, Opion engineers are hard at work on assorted countermeasures. One safeguard is inherent in the system: The software tracks opinions over time and makes comparisons with historical data. To trick the technology, a prankster would have to establish a long-term posting record that swayed others consistently.

Holtzman keeps a replica of a Pets.com sock puppet in his Herndon office. It serves as a reminder of those who have dreamed before him and failed. "When breaking ground on a new technology, it's worthless if you can't sell it," he says. "If you really want to change things, you have to make it real." And Holtzman wants to make catching a buzz a commonplace event. SA

Julie Wakefield is a technology writer based in Washington, D.C.

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Saying Yes to NO

The patent office is issuing a wealth of patents related to one of the most celebrated molecules of the past decade By GARY STIX

When three Americans won the Nobel Prize in Physiology or Medicine in 1998 for discoveries about nitric oxide, news coverage often focused on how this insight helped lead to the creation of Viagra. But the ubiquitous role that nitric oxide (NO) plays in the body—it does everything from fighting infections to combating cancer—has spurred a gold rush of patenting. One prominent researcher, Jonathan Stamler of Duke University and the Howard Hughes Medical Institute, has received more than 10 patents in the past 18 months alone for his work on NO; he estimates that he has applied for more than 50 in all.



JONATHAN STAMLER of Duke University has applied for more than 50 NO-associated patents.

A key recent patent relates to basic research performed by Stamler and his colleagues. The work showed that hemoglobin, besides shuttling oxygen to tissues and retrieving carbon dioxide, also delivers NO. Before, scientists had always believed that hemoglobin destroyed NO.

The new research demonstrated that the NO linked to hemoglobin allows blood vessels to expand or contract, depending on how much of the molecule is present. Patents received by Stamler and his colleague Joseph Bonaventura (U.S.: 6,153,186 and 6,203,789) provide a method for restoring NO in red blood cells that have been depleted through disease or while being stored in blood banks. The NO binds to cysteine, an amino acid in hemoglobin, to form a molecule called an S-nitrosothiol. When the red blood cells arrive at the capillaries, they release oxygen as well as the S-nitrosothiols. The NO in the S-nitrosothiols dilates blood vessels and thus allows oxygen to better reach tissues. NO-loaded blood cells could boost the effectiveness of blood transfusions done to treat sickle cell anemia and to replenish blood after heart attacks, strokes and other conditions in which tissues suffer from oxygen deficiency.

Another major finding achieved by Stamler's group was that NO binds to transcription factors and enzymes that regulate proteins in invading pathogens and in cancer and other abnormal cells. Stamler and Owen W. Griffith of the Medical College of Wisconsin won patents (U.S.: 6,057,367 and 6,180,824) for fighting microbes and cells gone awry by manipulating NO-related biochemical pathways. When the body is under attack from microorganisms, for instance, mammalian immune cells called macrophages produce NO, which attacks critical metabolic enzymes and other proteins in the pathogens. In a routine counterattack by the microbes, a sulfur-containing molecule, a thiol, wipes up the NO, a first line of defense against the invasion.

One aspect of the patents covers chemicals, such as a sulfoximine (which is related to a cancer chemotherapeutic agent), that inhibit enzymes and transcription factors that synthesize thiols in microorganisms but leave proteins in human cells relatively untouched. In addition, NO can be attached to an anticancer chemotherapeutic agent that homes in on a rapidly dividing cell, thereby enhancing its effects.

Stamler and Griffith's patent coverage is very extensive. Besides new drugs, one of the patents also covers molecules targeted by pharmaceuticals: any protein that microorganisms and other pathologically proliferating cells, such as those in cancer or in reblockage of an artery (restenosis), use to protect themselves against an NO onslaught. "This is a broad-based system, disruption of which may have major implications in biology and disease," Stamler notes. SA

Please let us know about interesting and unusual patents. Send suggestions to: patents@sciam.com

SAM OGDEN

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Baloney Detection

How to draw boundaries between science and pseudoscience, Part I

By MICHAEL SHERMER

When lecturing on science and pseudoscience at colleges and universities, I am inevitably asked, after challenging common beliefs held by many students, "Why should we believe you?" My answer: "You shouldn't."

I then explain that we need to check things out for ourselves and, short of that, at least to ask basic questions that get to the heart of the validity of any claim. This is what I call baloney detection, in deference to Carl Sagan, who coined the phrase "Baloney Detection Kit." To detect baloney—that is, to help discriminate between science and pseudoscience—I suggest 10 questions to ask when encountering any claim.

1. How reliable is the source of the claim?

Pseudoscientists often appear quite reliable, but when examined closely, the facts and figures they cite are distorted, taken out of context or occasionally even fabricated. Of course, everyone makes some mistakes. And as historian of science Daniel Kevles showed so effectively in his book *The Baltimore Affair,* it can be hard to detect a fraudulent signal within the background noise of sloppiness that is a normal part of the scientific process. The question is, Do the data and interpretations show signs of intentional distortion? When an independent committee established to investigate potential fraud scrutinized a set of research notes in Nobel laureate David Baltimore's laboratory, it revealed a surprising number of mistakes. Baltimore was exonerated because his lab's mistakes were random and nondirectional.

2. Does this source often make similar claims?

Pseudoscientists have a habit of going well beyond the facts. Flood geologists (creationists who believe that Noah's flood can account for many of the earth's geologic formations) consistently make outrageous claims that bear no relation to geological science. Of course, some great thinkers do frequently go beyond the data in their creative speculations. Thomas Gold of Cornell University is notorious for his radical ideas, but he has been right often enough that other scientists listen to what he has to say. Gold proposes, for example, that oil is not a fossil fuel at all but the by-product of a deep, hot biosphere (microorganisms living at unexpected depths within the crust). Hardly any earth scientists with whom I have spoken think Gold is right, yet they do not consider him a crank. Watch out for a pattern of fringe thinking that consistently ignores or distorts data.

3. Have the claims been verified by another source?

Typically pseudoscientists make statements that are unverified or verified only by a source within their own belief circle. We must ask, Who is checking the claims, and even who is checking the checkers? The biggest problem with the cold fusion debacle, for instance, was not that Stanley Pons and Martin Fleischman were wrong. It was that they announced their spectacular discovery at a press conference before other laboratories verified it. Worse, when cold fusion was not replicated, they continued to cling to their claim. Outside verification is crucial to good science.

4. How does the claim fit with what we know about how the world works?

An extraordinary claim must be placed into a larger context to see how it fits. When people claim that the Egyptian pyramids and the Sphinx were built more than 10,000 years ago by an unknown, advanced race, they are not presenting any context for that earlier civilization. Where are the rest of the artifacts of those people? Where are their works of art, their weapons, their clothing, their tools, their trash? Archaeology simply does not operate this way.

5. Has anyone gone out of the way to disprove the claim, or has only supportive evidence been sought?

This is the confirmation bias, or the tendency to seek confirmatory evidence and to reject or ignore disconfirmatory evidence. The confirmation bias is powerful, pervasive and almost impossible for any of us to avoid. It is why the methods of science that emphasize checking and rechecking, verification and replication, and especially attempts to falsify a claim, are so critical.

Next month in Part II I will expand the baloney detection process with five more questions that reveal how science works to detect its own baloney. SA

Michael Shermer is the founding publisher of Skeptic *magazine (www.skeptic.com) and the author of* How We Believe *and* The Borderlands of Science.

BRAD HINES

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Dissent in the Maelstrom

Maverick meteorologist Richard S. Lindzen keeps right on arguing that human-induced global warming isn't a problem By DANIEL GROSSMAN



KATHLEEN DOOHER

RICHARD S. LINDZEN: CLIMATE SKEPTIC

- **Born in 1940 and grew up in New York City; married with two children.**
- **Degrees from Harvard University; holds the endowed Alfred P. Sloan Professor of Meteorology chair at M.I.T.**
- **What he would do to global warming research if he held the federal purse strings: cut funding. "You would no longer have vested interests in the problem remaining" if funds were scarcer.**

Adviser to senators, think tanks and at least some of the president's men, Richard S. Lindzen holds a special place in today's heated debate about global warming. An award-winning scientist and a member of the National Academy of Sciences, he holds an endowed chair at the Massachusetts Institute of Technology and is the nation's most prominent and vocal scientist in doubting whether human activities pose any threat at all to the climate. Blunt and acerbic, Lindzen ill-tolerates naïveté. So it was with considerable trepidation recently that I parked in the driveway of his suburban home.

A portly man with a bushy beard and a receding hairline, Lindzen ushered me into his living room. Using a succession of cigarettes for emphasis, he explains that he never intended to be outspoken on climate change. It all began in the searing summer of 1988. At a high-profile congressional hearing, physicist James E. Hansen of the NASA Goddard Institute for Space Studies went public with his view: that scientists knew, "with a high degree of confidence," that human activities such as burning fossil fuel were warming the world. Lindzen was shocked by the media accounts that followed. "I thought it was important," he recalls, "to make it clear that the science was at an early and primitive stage and that there was little basis for consensus and much reason for skepticism." What he thought would be a couple of months in the public eye has turned into more than a decade of climate skepticism. "I did feel a moral obligation," he remarks of the early days, "although now it is more a matter of being stuck with a role."

It may be just a role, but Lindzen still plays it with gusto. His wide-ranging attack touches on computer modeling, atmospheric physics and research on past climate. His views appear in a steady stream of congressional testimonies, newspaper op-eds and public appearances. Earlier this year he gave a tutorial on climate change to President George W. Bush's cabinet.

It's difficult to untangle how Lindzen's views differ from those of other scientists because he questions so

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CLOUD COVER over the tropics could reduce global warming—or increase it.

much of what many others regard as settled. He fiercely disputes the conclusions of this past spring's report of the Intergovernmental Panel on Climate Change (IPCC)—largely considered to be the definitive scientific assessment of climate change—and those of a recent NAS report that reviewed the panel's work. (Lindzen was a lead author of one chapter of the IPCC report and was an author of the NAS report.) But, according to him, the country's leading scientists (who, he says, concur with him) prefer not to wade into the troubled waters of climate change: "It's the kind of pressure that the average scientist doesn't need." Tom M. L. Wigley, a prominent climate scientist at the National Center for Atmospheric Research, says it is "demonstrably incorrect" that top researchers are keeping quiet. "The best people in the world," he observes, have contributed to the IPCC report.

Lindzen agrees with the IPCC and most other climate scientists that the world has warmed about 0.5 degree Celsius over the past 100 years or so. He agrees that human activities have increased the amount of carbon dioxide in the atmosphere by about 30 percent. He parts company with the others when it comes to whether these facts are related. It's not that humans have no effect at all on climate. "They do," he admits, though with as much impact on the environment as when "a butterfly shuts its wings."

The IPCC report states that "most of the observed warming over the last 50 years" is of human origin. It says that late 20th-century temperatures shot up above anything the earth had experienced in the previous 1,000 years. Michael E. Mann, a geologist at the University of Virginia and a lead author of the IPCC's past-climate chapter, calls the spike "a change that is inconsistent with natural variability." Lindzen dismisses this analysis by questioning the method for determining historical temperatures. For the first 600 years of the 1,000-year chronology, he claims, researchers used tree rings alone to gauge temperature and only those from four separate locations. He calls the method used to turn tree-ring width into temperature hopelessly flawed.

Mann was flabbergasted when I questioned him about Lindzen's critique, which he called "nonsense" and "hogwash." A close examination of the IPCC report itself shows, for instance, that trees weren't the sole source of data—ice cores helped to reconstruct the temperatures of the first 600 years, too. And trees were sampled from 34 independent sites in a dozen distinct regions scattered around the globe, not four.

Past climate isn't the only point of divergence. Lindzen also says there is little cause for concern in the future. The key to his optimism is a parameter called "climate sensitivity." This variable represents the increase in global temperature expected if the amount of carbon dioxide in the air doubles over preindustrial levels—a level the earth is already one third of the way toward reaching. Whereas the IPCC and the NAS calculate climate sensitivity to be somewhere between 1.5 and 4.5 degrees C, Lindzen insists that it is in the neighborhood of 0.4 degree.

The IPCC and the NAS derived the higher range after incorporating positive feedback mechanisms. For instance, warmer temperatures will most likely shrink the earth's snow and ice cover, making the planet less reflective and thus hastening warming, and will also probably increase evaporation of water. Water vapor, in fact, is the main absorber of heat in the atmosphere.

But such positive feedbacks "have neither empirical nor theoretical foundations," Lindzen told the U.S. Senate commerce committee this past May. The scientist says negative, not positive, feedback rules the day. One hypothesis he has postulated is that increased warming actually dries out certain parts of the upper atmosphere. Decreased water vapor would in turn temper warming. Goddard's Hansen says that by raising this possibility Lindzen "has done a lot of good for the climate discussion." He hastens to add, however, "I'm very confident his basic criticism—

To Lindzen, climate research is "polluted with political rhetoric"; the science remains weak.

that climate models overestimate climate sensitivity—is wrong."

In March, Lindzen published what he calls "potentially the most important" paper he's written about negative feedback from water vapor. In it, he concludes that warming would decrease tropical cloud cover. Cloud cover is a complicated subject. Depending on factors that change by the minute, clouds can cool (by reflecting sunlight back into space) or warm (by trapping heat from the earth). Lindzen states that a reduction in tropical cloudiness would produce a marked cooling effect overall and thus serve as a stabilizing negative feedback.

But three research teams say Lindzen's paper is flawed. For example, his research was based on data collected from satellite images of tropical clouds. Bruce A. Wielicki of the NASA Langley Research Center believes that the images were not representative of the entire tropics. Using data from a different satellite, Wielicki and his group conclude, in a paper to appear in the *Journal of Climate,* that, on balance, warmer tropical clouds would have a slight heating, not a cooling, effect.

Looking back at the past decade of climate science, many researchers say computer models have improved, estimates of past climate are more accurate, and uncertainty is being reduced. Lindzen is not nearly so sanguine. In his mind the case for global warming is as poor as it was when his crusade began, in 1988. Climate research is, he insists, "heavily polluted by political rhetoric, with evidence remaining extremely weak." To Lindzen, apparently, the earth will take care of itself. SA

Daniel Grossman is a freelance writer in Watertown, Mass.

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On the Termination of Species

Ecologists' warnings of an ongoing mass extinction are being challenged by skeptics and largely ignored by politicians. In part that is because it is surprisingly hard to know the dimensions of the die-off, why it matters and how it can best be stopped

By W. Wayt Gibbs



CHERYL D. KNOTT

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END OF AN ORANGUTAN fixes our attention and seems to confirm our worst fears about the decline of biodiversity. But does our focus on charismatic animals blur a view of the big picture? The ape in this photograph died of natural causes. And a much greater part of the earth's evolutionary heritage rises from the banks and sits in the water than lies on the log.

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HILO, HAWAII—Among the scientists gathered here in August at the annual meeting of the Society for Conservation Biology, the despair was almost palpable. "I'm just glad I'm retiring soon and won't be around to see everything disappear," said P. Dee Boersma, former president of the society, during the opening night's dinner. Other veteran field biologists around the table murmured in sullen agreement.

At the next morning's keynote address, Robert M. May, a University of Oxford zoologist who presides over the Royal Society and until last year served as chief scientific adviser to the British government, did his best to disabuse any remaining optimists of their rosy outlook. According to his latest rough estimate, the extinction rate—the pace at which species vanish—accelerated during the past 100 years to roughly 1,000 times what it was before humans showed up. Various lines of argument, he explained, "suggest a speeding up by a further factor of 10 over the next century or so.... And that puts us squarely on the breaking edge of the sixth great wave of extinction in the history of life on Earth."

From there, May's lecture grew more depressing. Biologists and conservationists alike, he complained, are afflicted with a "total vertebrate chauvinism." Their bias toward mammals, birds and fish—when most of the diversity of life lies elsewhere—undermines scientists' ability to predict reliably the scope and consequences of biodiversity loss. It also raises troubling questions about the high-priority "hotspots" that environmental groups are scrambling to identify and preserve.

"Ultimately we have to ask ourselves why we care" about the planet's portfolio of species and its diminishment, May said. "This central question is a political and social question of values, one in which the voice of conservation scientists has no particular standing." Unfortunately, he concluded, of "the three kinds of argument we use to try to persuade politicians that all this is important . . . none is totally compelling."

Although May paints a truly dreadful picture, his is a common view for a field in which best-sellers carry titles such as *Requiem for Nature*. But is despair justified? *The Skeptical Environmentalist,* the new English translation of a recent book by Danish statistician Bjørn Lomborg, charges that reports of the death of biodiversity have been greatly exaggerated. In the face of such external skepticism, internal uncertainty and public apathy, some scientists are questioning the conservation movement's overriding emphasis on preserving rare species and the threatened hotspots in which they are concentrated. Perhaps, they suggest, we should focus instead on saving something equally at risk but even more valuable: evolution itself.

Overview/*Extinction Rates*

- Eminent ecologists warn that humans are causing a mass extinction event of a severity not seen since the age of dinosaurs came to an end 65 million years ago. But paleontologists and statisticians have called such comparisons into doubt.
- It is hard to know how fast species are disappearing. Models based on the speed of tropical deforestation or on the growth of endangered species lists predict rising extinction rates. But biologists' bias toward plants and vertebrates, which represent a minority of life, undermine these predictions. Because 90 percent of species do not yet have names, let alone censuses, they are impossible to verify.
- In the face of uncertainty about the decline of biodiversity and its economic value, scientists are debating whether rare species should be the focus of conservation. Perhaps, some suggest, we should first try to save relatively pristine—and inexpensive—land where evolution can progress unaffected by human activity.

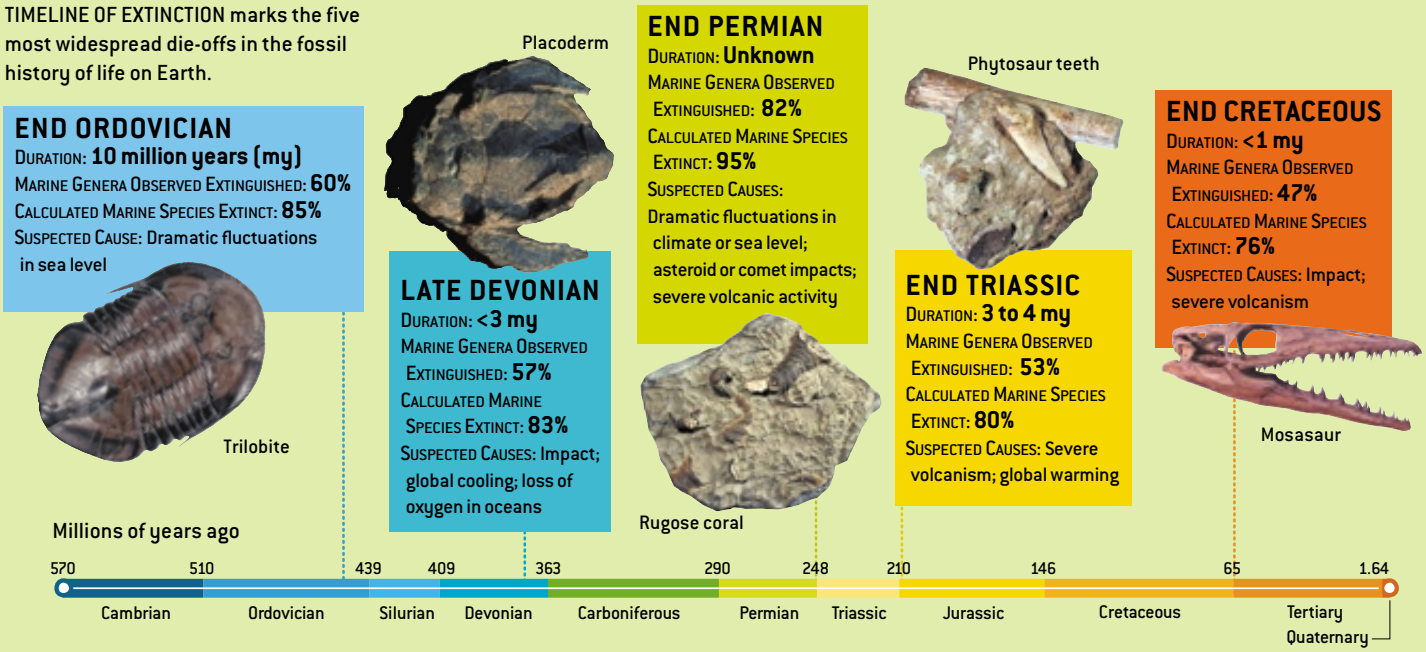
Doom ...

MAY'S CLAIM that humans appear to be causing a cataclysm of extinctions more severe than any since the one that erased the dinosaurs 65 million years ago may shock those who haven't followed the biodiversity issue. But it prompted no gasps from the conservation biologists. They have heard variations of this dire forecast since at least 1979, when Norman Myers guessed in *The Sinking Ark* that 40,000 species lose their last member each year and that one million would be extinct by 2000. In the 1980s Thomas Lovejoy similarly predicted that 15 to 20 percent would die off by 2000; Paul Ehrlich figured

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Mass Extinctions Past—and Present?

TIMELINE OF EXTINCTION marks the five most widespread die-offs in the fossil history of life on Earth.



With more than 1,100 species (*eight at right*) suspected to have disappeared in the past 500 years, ecologists fear a sixth mass extinction event is imminent. The die-offs so far, however, would probably not signal anything unusual to future paleontologists looking back at our time.

SPECIES *(Scientific name)*	LAST SEEN, LOCATION	EXTINCTION CAUSES
Deepwater ciscoe (*Coregonus johannae*)	1952, Lakes Huron and Michigan	Overfishing, hybridization
Pupfish *(Cyprinodon ceciliae)*	1988, Ojo de Agua La Presa, Mexico	Loss of food supply
Dobson's fruit bat *(Dobsonia chapmani)*	1970s, Cebu Islands, Philippines	Forest destruction, overhunting
Caribbean monk seal *(Monachus tropicalis)*	1950s, Caribbean Sea	Overhunting, harassment
Guam flycatcher *(Myiagra freycinetI)*	1983, Guam	Predation by introduced brown tree snakes
Kaua'i 'O'o *(Moho braccatus)*	1987, Island of Kaua'i, Hawaii	Disease, rat predation
Xerces Blue Butterfly *(Glaucopsyche xerces)*	1941, San Francisco Peninsula	Land conversion
Tobias' Caddis Fly *(Hydropsyche tobiasi)*	1950s, Rhine River, Germany	Industrial and urban pollution

SOURCES: Committee on Recently Extinct Organisms; BirdLife International; Xerces Society; World Wildlife Fund

LESTER V. BERGMAN *Corbis (trilobite)*; JAMES L. AMOS *Corbis (Placoderm)*; RICHARD PASELK *Humboldt State University/Natural History Museum (Rugose coral and Phytosaur teeth)*; MIKE EVERHART *Oceans of Kansas Paleontology (Mosasaur)*

half would be gone by now. "I'm reasonably certain that [the elimination of one fifth of species] didn't happen," says Kirk O. Winemiller, a fish biologist at Texas A&M University who just finished a review of the scientific literature on extinction rates.

More recent projections factor in a slightly slower demise because some doomed species have hung on longer than anticipated. Indeed, a few have even returned from the grave. "It was discovered only this summer that the Bavarian vole, continental Eurasia's one and only presumed extinct mammal [since 1500], is in fact still with us," says Ross D. E. MacPhee, curator of mammalogy at the American Museum of Natural History (AMNH) in New York City.

Still, in the 1999 edition of his often-quoted book *The Diversity of Life,* Harvard University biologist E. O. Wilson cites current estimates that between 1 and 10 percent of species are extinguished every decade, at least 27,000 a year. Michael J. Novacek, AMNH's provost of science, wrote in a review article this spring that "figures approaching 30 percent extermination of all species by the mid-21st century are not unrealistic." And in a 1998 survey of biologists, 70 percent said they believed that a mass extinction is in progress; a third of them expected to lose 20 to 50 percent of the world's species within 30 years.

"Although these assertions of massive extinctions of species have been repeated everywhere you look, they do not equate with the available evidence," Lomborg argues in *The Skeptical Environmentalist*. A professor of statistics and political science at the University of Århus, he alleges that environmentalists have ignored recent evidence that tropical deforestation is not taking the toll that was feared. "No well-investigated group of animals shows a pattern of loss that is consistent with greatly heightened extinction rates," MacPhee concurs. The best models, Lomborg suggests, project an extinction rate of 0.15 percent of species per decade, "not a catastrophe but a problem—one of many that mankind still needs to solve."

... or Gloom?

"IT'S A TOUGH question to put numbers on," Wilson allows. May agrees but says "that isn't an argument for not asking the question" of whether a mass extinction event is upon us.

To answer that question, we need to know three things: the

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The Portfolio of Life

How severe is the extinction crisis? That depends in large part on how many species there are altogether. The greater the number, the more species will die out every year from natural causes and the more new ones will naturally appear. But although the general outlines of the tree of life are clear, scientists are unsure how many twigs lie at the end of each branch. When it comes to bacteria, viruses, protists and archaea (a whole kingdom of single-celled life-forms discovered just a few decades ago), microbiologists have only vague notions of how many branches there are.

Birds, fish, mammals and plants are the exceptions. Sizing up the global workforce of about 5,000 professional taxonomists, zoologist Robert M. May of the University of Oxford noted that about equal numbers study vertebrates, plants and invertebrates. "You may wish to think this record reflects some judicious appreciation of what's important," he says. "My view of that is: absolute garbage. Whether you are interested in how ecosystems evolved, their current functioning or how they are likely to respond to climate change, you're going to learn a lot more by looking at soil microorganisms than at charismatic vertebrates."

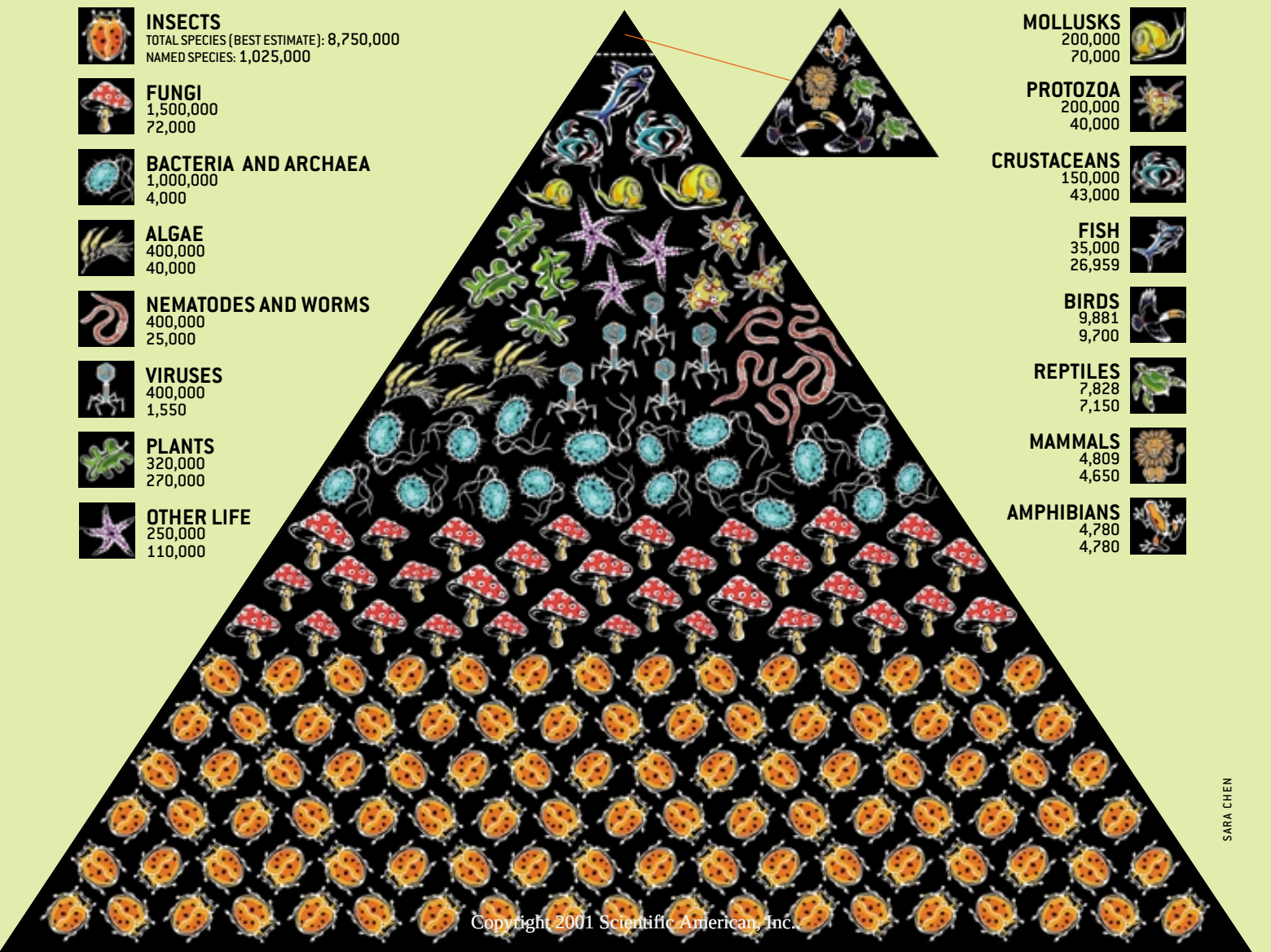
For every group except birds, says Peter Hammond of the National History Museum in London, new species are now being discovered faster than ever before, thanks to several new international projects. An All Taxa Biodiversity Inventory under way in Great Smoky Mountains National Park in North Carolina and Tennessee has discovered 115 species—80 percent of them insects or arachnids—in its first 18 months of work. Last year 40 scientists formed the All Species Project, a society devoted to the (probably quixotic) goal of cataloguing every living species, microbes included, within 25 years.

Other projects, such as the Global Biodiversity Information Facility and Species2000, are building Internet databases that will codify species records that are now scattered among the world's museums and universities. If biodiversity is defined in strictly pragmatic terms as the variety of life-forms we know about, it is growing prodigiously.

PYRAMID OF DIVERSITY

TO A FIRST APPROXIMATION, all multicellular species are insects. Biologists know the least about the true diversity and ecological importance of the very groups that are most common.

SOURCES: Encyclopedia of Biodiversity, *edited by S. A. Levin; "Biodiversity Hotspots for Conservation Priorities," by N. Myers et al. in* Nature, *Vol. 403, pages 853–858, February 24, 2000; William Eschemeyer (fish species); Marc Van Regenmortel (virus species); IUCN Red List 2000*



SARA CHEN

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natural (or "background") extinction rate, the current rate and whether the pace of extinction is steady or changing. The first step, Wilson explains, is to work out the mean life span of a species from the fossil record. "The background extinction rate is then the inverse of that. If species are born at random and all live exactly one million years—and it varies, but it's on that order—then that means one species in a million naturally goes extinct each year," he says.

In a 1995 article that is still cited in almost every scientific paper on this subject (even in Lomborg's book), May used a similar method to compute the background rate. He relied on estimates that put the mean species life span at five million to 10 million years, however; he thus came up with a rate that is five to 10 times lower than Wilson's. But according to paleontologist David M. Raup (then at the University of Chicago), who published some of the figures May and Wilson relied on, their calculations are seriously flawed by three false assumptions.

One is that species of plants, mammals, insects, marine invertebrates and other groups all exist for about the same time. In fact, the typical survival time appears to vary among groups by a factor of 10 or more, with mammal species among the least durable. Second, they assume that all organisms have an equal chance of making it into the fossil record. But paleontologists estimate that fewer than 4 percent of all species that ever lived are preserved as fossils. "And the species we do see are the widespread, very successful ones," Raup says. "The weak species confined to some hilltop or island all went extinct before they could be fossilized," adds John Alroy of the University of California at Santa Barbara.

The third problem is that May and Wilson use an average life span when they should use a median. Because "the vast majority of species are short-lived," Raup says, "the average is distorted by the very few that have very long life spans." All three oversimplifications underestimate the background rate—and make the current picture scarier in comparison.

Earlier this year U.C.S.B. biomathematician Helen M. Regan and several of her colleagues published the first attempt ever to correct for the strong biases and uncertainties in the data. They looked exclusively at mammals, the best-studied group. They estimated how many of the mammals now living, and how many of those recently extinguished, would show up as fossils. They also factored in the uncertainty for each number rather than relying on best guesses. In the end they concluded that "the current rate of mammalian extinction lies between 17 and 377 times the background extinction rate." The best estimate, they wrote, is a 36- to 78-fold increase.

Regan's method is still imperfect. Comparing the past 400 years with the previous 65 million unavoidably assumes, she says, "that the current extinction rate will be sustained over millions of years." Alroy recently came up with a way to measure the speed of extinctions that doesn't suffer from such assumptions. Over the past 200 years, he figures, the rate of loss among mammal species has been some 120 times higher than natural.

A Grim Guessing Game

ATTEMPTS TO FIGURE out the current extinction rate are fraught with even more uncertainties. The international conservation organization IUCN keeps "Red Lists" of organisms suspected to be extinct in the wild. But MacPhee complains that "the IUCN methodology for recognizing extinction is not sufficiently rigorous to be reliable." He and other extinction experts have formed the Committee on Recently Extinct Organisms, which combed the Red Lists to identify those species that were clearly unique and that had not been found despite a reasonable search. They certified 60 of the 87 mammals listed by IUCN as extinct but claim that only 33 of the 92 freshwater fish presumed extinct by IUCN are definitely gone forever.

"If you are looking for hard evidence of tens or hundreds or thousands of species disappearing each year, you aren't going to find it." —KIRK O. WINEMILLER, TEXAS A&M

For every species falsely presumed absent, however, there may be hundreds or thousands that vanish unknown to science. "We are uncertain to a factor of 10 about how many species we share the planet with," May points out. "My guess would be roughly seven million, but credible guesses range from five to 15 million," excluding microorganisms.

Taxonomists have named approximately 1.8 million species, but biologists know almost nothing about most of them, especially the insects, nematodes and crustaceans that dominate the animal kingdom. Some 40 percent of the 400,000 known beetle species have each been recorded at just one location—and with no idea of individual species' range, scientists have no way to confirm its extinction. Even invertebrates known to be extinct often go unrecorded: when the passenger pigeon was eliminated in 1914, it took two species of parasitic lice with it. They still do not appear on IUCN's list.

"It is extremely difficult to observe an extinction; it's like seeing an airplane crash," Wilson says. Not that scientists aren't trying. Articles on the "biotic holocaust," as Myers calls it, usually figure that the vast majority of extinctions have been in the tropical Americas. Freshwater fishes are especially vulnerable, with more than a quarter listed as threatened. "I work in Venezuela, which has substantially more freshwater fishes than all of North America. After 30 years of work, we've done a reasonable job of cataloguing fish diversity there," observes Winemiller of Texas A&M, "yet we can't point to one documented case of extinction."

A similar pattern emerges for other groups of organisms, he

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claims. "If you are looking for hard evidence of tens or hundreds or thousands of species disappearing each year, you aren't going to find it. That could be because the database is woefully inadequate," he acknowledges. "But one shouldn't dismiss the possibility that it's not going to be the disaster everyone fears."

The Logic of Loss

THE DISASTER SCENARIOS are based on several independent lines of evidence that seem to point to fast and rising extinction rates. The most widely accepted is the species-area relation. "Generally speaking, as the area of habitat falls, the number of species living in it drops proportionally by the third root to the sixth root," explains Wilson, who first deduced this equation more than 30 years ago. "A middle value is the fourth root, which means that when you eliminate 90 percent of the habitat, the number of species falls by half."

"From that rough first estimate and the rate of the destruction of the tropical forest, which is about 1 percent a year," Wilson continues, "we can predict that about one quarter of 1 percent of species either become extinct immediately or are doomed to much earlier extinction." From a pool of roughly 10 million species, we should thus expect about 25,000 to evaporate annually.

Lomborg challenges that view on three grounds, however. Species-area relations were worked out by comparing the number of species on islands and do not necessarily apply to fragmented habitats on the mainland. "More than half of Costa Rica's native bird species occur in largely deforested countryside habitats, together with similar fractions of mammals and butterflies," Stanford University biologist Gretchen Daily noted recently in *Nature*. Although they may not thrive, a large fraction of forest species may survive on farmland and in woodlots—for how long, no one yet knows.

That would help explain Lomborg's second observation, which is that in both the eastern U.S. and Puerto Rico, clearance of more than 98 percent of the primary forests did not wipe out half of the bird species in them. Four centuries of logging "resulted in the extinction of only one forest bird" out of 200 in the U.S. and seven out of 60 native species in Puerto Rico, he asserts.

Such criticisms misunderstand the species-area theory, according to Stuart L. Pimm of Columbia University. "Habitat destruction acts like a cookie cutter stamping out poorly mixed dough," he wrote last year in *Nature*. "Species found only within the stamped-out area are themselves stamped out. Those found more widely are not."

Of the 200 bird types in the forests of the eastern U.S., Pimm states, all but 28 also lived elsewhere. Moreover, the forest was cleared gradually, and gradually it regrew as farmland was abandoned. So even at the low point, around 1872, woodland covered half the extent of the original forest. The species-area theory predicts that a 50 percent reduction should knock out 16 percent of the endemic species: in this case, four birds. And four species did go extinct. Lomborg discounts one of those four that may have been a subspecies and two others that perhaps succumbed to unrelated insults.

But even if the species-area equation holds, Lomborg responds, official statistics suggest that deforestation has been slowing and is now well below 1 percent a year. The U.N. Food and Agriculture Organization recently estimated that from 1990 to 2000 the world's forest cover dropped at an average annual rate of 0.2 percent (11.5 million hectares felled, minus 2.5 million hectares of new growth).

Annual forest loss was around half a percent in most of the tropics, however, and that is where the great majority of rare and threatened species live. So although "forecasters may get these figures wrong now and then, perhaps colored by a desire to sound the alarm, this is just a matter of timescale," replies Carlos A. Peres, a Brazilian ecologist at the University of East Anglia in England.

An Uncertain Future

ECOLOGISTS HAVE TRIED other means to project future extinction rates. May and his co-workers watched how vertebrate species moved through the threat categories in IUCN's database over a four-year period (two years for plants), projected those very small numbers far into the future and concluded that extinction rates will rise 12- to 55-fold over the next 300 years. Georgina M. Mace, director of science at the Zoological Society of London, came to a similar conclusion by combining models that plot survival odds for a few very well known species. Entomologist Nigel E. Stork of the Natural History Museum in London noted that a British bird is 10 times more likely than a British bug to be endangered. He then extrapolated such ratios to the rest of the world to predict 100,000 to 500,000 insect extinctions by 2300. Lomborg favors this latter model, from which he concludes that "the rate for all animals will remain below 0.208 percent per decade and probably be below 0.7 percent per 50 years."

It takes a heroic act of courage for any scientist to erect such

Extinction *Filters*

SURVIVAL OF THE FITTEST takes on a new meaning when humans develop a region. Among four Mediterranean climate regions, those developed more recently have lost larger fractions of their vascular plant species in modern times. Once the species least compatible with agriculture are filtered out by "artificial selection," extinction rates seem to fall.

REGION (in order of development)	EXTINCT (per 1,000)	THREATENED (percent)
Mediterranean	1.3	14.7
South African Cape	3.0	15.2
California	4.0	10.2
Western Australia	6.6	17.5

SOURCE: "Extinctions in Mediterranean Areas." Werner Greuter in Extinction Rates. *Edited by J. H. Lawton and R. H. May. Oxford University Press, 1995*

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FRANS LANTING *Minden Pictures*

WEALTH OF RAIN FORESTS, this one in Borneo, is largely unmeasured, both in biological and economic terms.

long and broad projections on such a thin and lopsided base of data. Especially when, according to May, the data on endangered species "may tell us more about the vagaries of sampling efforts, of taxonomists' interests and of data entry than about the real changes in species' status."

Biologists have some good theoretical reasons to fear that even if mass extinction hasn't begun yet, collapse is imminent. At the conference in Hilo, Kevin Higgins of the University of Oregon presented a computer model that tracks artificial organisms in a population, simulating their genetic mutation rates, reproductive behavior and ecological interactions. He found that "in small populations, mutations tend to be mild enough that natural selection doesn't filter them out. That dramatically shortens the time to extinction." So as habitats shrink and populations are wiped out—at a rate of perhaps 16 million a year, Daily has estimated—"this could be a time bomb, an extinction event occurring under the surface," Higgins warns. But proving that that bomb is ticking in the wild will not be easy.

And what will happen to fig trees, the most widespread plant genus in the tropics, if it loses the single parasitic wasp variety that pollinates every one of its 900 species? Or to the 79 percent of canopy-level trees in the Samoan rain forests if hunters kill off the flying foxes on which they depend? Part of the reason so many conservationists are so fearful is that they expect the arches of entire ecosystems to fall once a few "keystone" species are removed.

Others distrust that metaphor. "Several recent studies seem to show that there is some redundancy in ecosystems," says Melodie A. McGeoch of the University of Pretoria in South Africa, although she cautions that what is redundant today may not be redundant tomorrow. "It really doesn't make sense to think the majority of species would go down with marginally higher pressures than if humans weren't on the scene," MacPhee adds. "Evolution should make them resilient."

If natural selection doesn't do so, artificial selection might, according to work by Werner Greuter of the Free University of Berlin, Thomas M. Brooks of Conservation International and others. Greuter compared the rate of recent plant extinctions in four ecologically similar regions and discovered that the longest-settled, most disturbed area—the Mediterranean—had the lowest rate. Plant extinction rates were higher in California and South Africa, and they were highest in Western Australia. The solution to this apparent paradox, they propose, is that species that cannot coexist with human land use tend to die out soon after agriculture begins. Those that are left are better equipped to dodge the darts we throw at them. Human-induced extinctions may thus fall over time.

If true, that has several implications. Millennia ago our ancestors may have killed off many more species than we care to

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Why Biodiversity Doesn't (Yet) Pay

FOZ DO IGUAÇU, BRAZIL—At the International Congress of Entomologists last summer, Ebbe Nielsen, director of the Australian National Insect Collection in Canberra, reflected on the reasons why, despite the 1992 Convention on Biological Diversity signed here in Brazil by 178 countries, so little has happened since to secure the world's threatened species. "You and I can say extinction rates are too high and we have to stop it, but to convince the politicians we have to have convincing reasons," he said. "In developing countries, the economic pressures are so high, people use whatever they can find today to survive until tomorrow. As long as that's the case, there will be no support for biodiversity at all."

Not, that is, unless it can be made more profitable to leave a forest standing or a wetland wet than it is to convert the land to farm, pasture or parking lot. Unfortunately, time has not been kind to the several arguments environmentalists have made to assign economic value to each one of perhaps 10 million species.

A Hedge against Disease and Famine

"Narrowly utilitarian arguments say: The incredible genetic diversity contained in the population and species diversity that we are heirs to is ultimately the raw stuff of tomorrow's biotechnological revolution," observes Robert May of Oxford. "It is the source of new drugs." Or new foods, adds E. O. Wilson of Harvard, should something happen to the 30 crops that supply 90 percent of the calories to the human diet, or to the 14 animal species that make up 90 percent of our livestock.

"Some people who say that may even believe it," May continues. "I don't. Give us 20 or 30 years and we will design new drugs from the molecule up, as we are already beginning to do."

Hopes were raised 10 years ago by reports that Merck had paid $1.14 million to InBio, a Costa Rican conservation group, for novel chemicals extracted from rain-forest species. The contract would return royalties to InBio if any of the leads became drugs. But none have, and Merck terminated the agreement in 1999. Shaman Pharmaceuticals, founded in 1989 to commercialize traditional medicinal plants, got as far as late-stage clinical trials but then went bankrupt. And given, as Wilson himself notes in *The Diversity of Life,* that more than 90 percent of the known varieties of the basic food plants are on deposit in seed banks, national parks are hardly the cheapest form of insurance against crop failures.

Ecosystem Services

"Potentially the strongest argument," May says, "is a broadly utilitarian one: ecological systems deliver services we're only just beginning to think of trying to estimate. We do not understand how much you can simplify these systems and yet still have them function. As Aldo Leopold once said, the first rule of intelligent tinkering is to keep all the pieces."

The trouble with this argument, explains Columbia University economist Geoffrey Heal, is that "it does not make sense to ask about the value of replacing a life-support system." Economics can only assign values to things for which there are markets, he says. If all oil were to vanish, for example, we could switch to alternative fuels that cost $50 a barrel. But that does not determine the price of oil.

And although recent experiments suggest that removing a large fraction of species from a small area lowers its biomass and ability to soak up carbon dioxide, scientists cannot say yet whether the principle applies to whole ecosystems. "It may be that a grievously simplified world—the world of the cult movie *Blade Runner*—can be so run that we can survive in it," May concedes.

A Duty of Stewardship

Because science knows so little of the millions of species out there, let alone what complex roles each one plays in the ecosystems it inhabits, it may never be possible for economics to come to the aid of endangered species. A moral argument may thus be the best last hope—certainly it is appeals to leaders' sense of stewardship that have accomplished the most so far. But is it hazardous for scientists to make it?

They do, of course, in various forms. To Wilson, "a species is a masterpiece of evolution, a million-year-old entity encoded by five billion genetic letters, exquisitely adapted to the niche it inhabits." For that reason, conservation biologist David Ehrenfeld proposed in *The Arrogance of Humanism,* "long-standing existence in Nature is deemed to carry with it the unimpeachable right to continued existence."

Winning public recognition of such a right will take much education and persuasion. According to a poll last year, fewer than one quarter of Americans recognized the term "biological diversity." Three quarters expressed concern about species and habitat loss, but that is down from 87 percent in 1996. And May observes that the concept of biodiversity stewardship "is a developed-world luxury. If we were in abject poverty trying to put food in the mouth of the fifth child, the argument would have less resonance."

But if scientists "proselytize on behalf of biodiversity"—as Wilson, Lovejoy, Ehrlich and many others have done—they should realize that "such work carries perils," advises David Takacs of California State University at Monterey Bay. "Advocacy threatens to undermine the perception of value neutrality and objectivity that leads laypersons to listen to scientists in the first place." And yet if those who know rare species best and love them most cannot speak openly on their behalf, who will?

FRANS LANTING *Minden Pictures*

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think about in Europe, Asia and other long-settled regions. On the other hand, we may have more time than we fear to prevent future catastrophes in areas where humans have been part of the ecosystem for a while—and less time than we hope to avoid them in what little wilderness remains pristine.

"The question is how to deal with uncertainty, because there really is no way to make that uncertainty go away," Winemiller argues. "We think the situation is extremely serious; we just don't think the species extinction issue is the peg the conservation movement should hang its hat on. Otherwise, if it turns out to be wrong, where does that leave us?"

Long-Term Savings

IT COULD LEAVE conservationists with less of a sense of urgency and with a handful of weak political and economic arguments [*see box on opposite page*]. It might also force them to realize that "many of the species in trouble today are in fact already members of the doomed, living dead," as David S. Woodruff wrote in the *Proceedings of the National Academy of Sciences* this past May. "Triage" is a dirty word to many environmentalists. "Unless we say no species loss is acceptable, then we have no line in the sand to defend, and we will be pushed back and back as losses build," Brooks argued at the Hilo meeting. But losses are inevitable, Wilson says, until the human population stops growing.

"I call that the bottleneck," Wilson elaborates, "because we have to pass through that scramble for remaining resources in order to get to an era, perhaps sometime in the 22nd century, of declining population. Our goal is to carry as much of the biodiversity through as possible." Biologists are divided, however, on whether the few charismatic species now recognized as endangered should determine what gets pulled through the bottleneck.

"The argument that when you protect birds and mammals, the other things come with them just doesn't stand up to close examination," May says. A smarter goal is "to try to conserve the greatest amount of evolutionary history." Far more valuable than a panda or rhino, he suggests, are relic life-forms such as the tuatara, a large iguanalike reptile that lives only on islets off the coast of New Zealand. Just two species of tuatara remain from a group that branched off from the main stem of the reptilian evolutionary tree so long ago that this couple make up a genus, an order and almost a subclass all by themselves.

But Woodruff, who is an ecologist at the University of California at San Diego, invokes an even broader principle. "Some of us advocate a shift from saving things, the products of evolution, to saving the underlying process, evolution itself," he writes. "This process will ultimately provide us with the most cost-effective solution to the general problem of conserving nature."

There are still a few large areas where natural selection alone determines which species succeed and which fail. "Why not save functioning ecosystems that haven't been despoiled yet?" Winemiller asks. "Places like the Guyana shield region of South America contain far more species than some of the so-called hotspots." To do so would mean purchasing tracts large enough to accommodate entire ecosystems as they roll north and south in response to the shifting climate. It would also mean prohibiting all human uses of the land. It may not be impossible: utterly undeveloped wilderness is relatively cheap, and the population of potential buyers has recently exploded.

"It turns out to be a lot easier to persuade a corporate CEO or a billionaire of the importance of the issue than it is to convince the American public," Wilson says. "With a Ted Turner or a Gordon Moore or a Craig McCaw involved, you can accomplish almost as much as a government of a developed country would with a fairly generous appropriation."

"Maybe even more," agrees Richard E. Rice, chief economist for Conservation International. With money from Moore, McCaw, Turner and other donors, CI has outcompeted logging companies for forested land in Suriname and Guyana. In Bolivia, Rice reports, "we conserved an area the size of Rhode Island for half the price of a house in my neighborhood," and the Nature Conservancy was able to have a swath of rain forest as big as Yellowstone National Park set aside for a mere $1.5 million. In late July, Peru issued to an environmental group the country's first "conservation concession"—essentially a renewable lease for the right to *not* develop the land—for 130,000 hectares of forest. Peru has now opened some 60 million hectares of its public forests to such concessions, Rice says. And efforts are under way to negotiate similar deals in Guatemala and Cameroon.

"Even without massive support in public opinion or really effective government policy in the U.S., things are turning upward," Wilson says, with a look of cautious optimism on his face. Perhaps it is a bit early to despair after all. SA

"It turns out to be a lot easier to persuade a corporate CEO or a billionaire of the importance of the issue than it is to convince the American public." —EDWARD O. WILSON, HARVARD UNIVERSITY

W. Wayt Gibbs is senior writer.

MORE TO EXPLORE

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OFFERING A GLIMPSE of a future with rewritable periodicals, this E Ink Corporation prototype "prints" text using electronic ink. Voltages are supplied to the ink by a thin-film-transistor panel, from IBM. The panel is 800 by 600 pixels; each pixel is formed by charged pigment—the "ink." Electrically erasable programmable memory sticks (*sitting atop display, at right*) are used in setting the text.

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Digital "paper" that displays changing text and graphics would ideally marry the best features of traditional printed materials with those of video screens. Companies are racing to realize that promise using two competing technologies. Already retailers are testing cost-saving changeable e-ink signage.

PAPER CHASE

Pliable, updatable e-newspapers, e-books and even an e-SCIENTIFIC AMERICAN could be here within a decade.

BY STEVE DITLEA

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It offers excellent resolution and high contrast under a wide range of viewing angles, requires no external power to retain its image, weighs little, costs less and is remarkably flexible (literally and figuratively)—unlike today's computer displays. No wonder traditional ink on paper continues to flourish in a digital world that was expected to all but do away with it.

Yet ink on paper is lacking in one of the essential traits of computer displays: instantaneous erasure and reuse, millions of times without wearing out. Electronic ink on paper with this ability could usher in an era of store signs and billboards that could be updated without pulping acres of trees; of e-books that embody the familiar tactile interface of traditional books; of magazines and newspapers delivered wirelessly to thin, flexible page displays, convenient for reading, whether on crowded subways or desert islands.

There have been intermittent efforts to produce such electronic paper over the past three decades, but only recently has research gone into full swing. The day when *Scientific American* and other periodicals are routinely published in this medium may come before 2010, thanks to competition between two start-up firms. Both companies are offshoots of major research institutions: the Xerox Palo Alto Research Center (PARC) and the Massachusetts Institute of Technology Media Laboratory. Both firms base their core technologies on tiny, electrically charged beads, with the imaging capability controlled electronically. And they are not only racing each other to commercialize their efforts but are also anticipating competition from the organic light-emitting diodes that are beginning to emerge from laboratories.

Spinning Off Electric Paper

THE EARLIEST ATTEMPT at "electric paper," as it was originally called, came as a response to the poor visual quality of the computer displays available in the early 1970s. "The CRTs [cathode-ray tubes] were too dim," recalls Nicholas K. Sheridon. "I wanted to find a display material with as many of the properties of paper as possible. Finding a paper substitute was not my main motivation."

When SCIENTIFIC AMERICAN last caught up with Sheridon three years ago [see "The Reinvention of Paper," by W. Wayt Gibbs, September 1998], he was a senior research fellow at PARC, demonstrating prototypes of what Xerox was by then calling "electronic reusable paper." More than 20 years earlier at PARC he had come up with the basic idea for this display medium, embedding plastic beads scarcely the width of a human hair in a flexible transparent film. Each bead is two-toned: one half white and one half black, with an opposing electrical charge on each half. Apply an appropriate electric field to the transparent surface, and a bead can be rotated to lock either a white or black dot onto the viewing plane—creating, in effect, ink that twists itself into the right place.



THREE DECADES AFTER his initial vision of creating an electronic display with as many of the features of paper as possible, Nicholas K. Sheridon of Gyricon Media demonstrates the feasibility of SmartPaper displays. The displays, which are now being marketed under the MaestroSign brand, could save individual stores thousands of dollars in signage costs.

SAM OGDEN (*pages 50 and 51*); ERIC MILLETTE (*this page*)

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JOSEPH JACOBSON of the M.I.T. Media Lab and E Ink seeks to create the effect of real paper that prints itself. His ultimate goal is a cybercodex, "the last book," a bound volume of hundreds of e-ink pages with enough memory chips to store the entire contents of the Library of Congress.

SAM OGDEN

Sheridon called his invention Gyricon, Greek for "rotating image." Soon shelved by Xerox managers who were more interested in exploring new printing technologies than in making displays, the reusable-paper concept wasn't revived until 15 years later—hence Sheridon's demo described in these pages at the time.

He would have to wait still longer for his technology to make its way into a commercial product. First it had to be spun off into a separate company. In December 2000 Gyricon Media was launched as an independent venture headquartered in Palo Alto, Calif. (with Xerox retaining a majority financial stake in the company). By March 2001 the new firm made its first product announcement at the GlobalShop trade show for retail store displays in Chicago. On the floor of the McCormick Place convention center, Sheridon, now Gyricon Media's research director, could be seen admiring a smoky green 11-by-14-inch panel on an aluminum stand, the kind you find on department store tables. This sign cycled through several sales messages and the price "$89.99" in slightly speckled type, and it would be powered by its three AA batteries for up to two years. Nearly 30 years after its original inspiration, Sheridon's electric paper was finally available—with limitations.

This prototype of what is now being marketed as SmartPaper was to be field-tested throughout the second half of 2001 in 15 signs at the Macy's department store in Bridgewater, N.J. Resolution was the equivalent of a modest 100 dots per inch (dpi). In comparison, the resolution of the print version of this magazine is 1,200 dpi. And because inflexible electrodes were used to activate the pliant SmartPaper material (a silicone rubber film soaked in oil to allow the bichromate beads to rotate), this version of e-paper was rigid as a board.

By 2002 Sheridon expects the commercial sale of similarly sized signs that can be easily updated via a wireless network. To a retail client like Federated Department Stores, Macy's parent company, which is currently spending more than $250,000 a week on changing its in-store signs, such renewable signage could prove highly desirable. Also due out next year are smaller SmartPaper signs meant to keep prices up-to-date on supermarket shelves, where inaccurate numbers can turn into expensive fines under item-pricing laws.

The pliable, reusable e-newspaper or e-magazine of the future "could happen in a few years," Sheridon has predicted on several occasions. He happens to have a concept model: a slit aluminum cylinder from which he pulls out a sheet of SmartPaper, papyrus scroll–like. In a working model, an array of electrodes along the edge of the cylinder would imprint up-to-the-minute news or feature stories on the paper's flexible, rubbery surface; plastic sheets would protect the paper from being damaged. Smaller-size beads necessary for higher resolution are on the way. As for a full range of colors, Sheridon has been issued a patent for subtractive color using transparent Gyricon beads with thin disks of color filter material in cyan, magenta and yellow, each addressable by different voltage levels.

Nevertheless, as paperlike as it may become, this electronic paper may never feel exactly like the original. Sheridon admits, "It will never be as light as paper. Paper is about four mils thick; this will always be 12 or 15 mils thick. But it doesn't have to exactly replicate paper to be useful."

Making a Mark with E-Ink

REAL PAPER ABLE to print itself was the starting point for Gyricon Media's principal rival in the digital paper market. Independent of Sheridon, in 1995 Joseph Jacobson, then a Stanford University physics postdoctoral researcher, was looking for an interesting problem to tackle. He came up with the notion of a book full of pages that could be electronically reconfigured to display the text of *King Lear* or *General Relativity* or any of hundreds of other tomes stored in silicon memory in the book's spine.

For his imaging technology, Jacobson turned to electrophoresis, the movement imparted by an electric field to charged

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particles that are suspended in a liquid. In place of pigment-carrying beads, he used transparent polymer microcapsules containing a blue liquid dye and white particles. When the positively charged particles of white titanium dioxide remain on the viewable side of the microcapsules, they produce a white page; a negative charge on an electrode below a capsule will draw these particles to the other side, creating an inklike image in their place—until an opposite electrical pulse sends the white pigment back. Reversing this process produces white letters on a dark background. Suspended in water, the microcapsules can be printed on paper or electrode-bearing materials just like ink. Jacobson called this "electrophoretic ink," or e-ink.

Appointed to an assistant professor position at the M.I.T. Media Lab in 1995, he continued his research into e-ink with two of his undergraduate students, J. D. Albert and Barrett Comiskey. In 1997 the three of them, along with Harvard Business School graduate Russell J. Wilcox, founded E Ink Corporation in Cambridge, Mass. The start-up soon attracted funds from venture-capital firms, corporate investors, including Motorola and the Hearst Corporation, and an R&D grant from the Defense Advanced Research Projects Agency (DARPA).

In 1999 E Ink introduced the first store signs using its technology. The rigid signs, released under the brand name Immedia, measured six by four feet and displayed large, white italic characters (with resolution equivalent to 2 dpi) on a blue background. They were tested in several J. C. Penney stores, as well as by the *Arizona Republic* newspaper for headline displays, and even in sandwich boards worn on city streets for Yahoo. Research found the signs effective in increasing store traffic and departmental sales for E Ink's customers in retailing, but customers wanted a greater choice of fonts, colors and graphics. Until E Ink can develop its next generation of store signage, it has withdrawn from this market.

Jacobson is not involved in E Ink's day-to-day operations (he serves on its board of directors, while devoting most of his time to his position as director of the Molecular Machines Research Group at the Media Lab). In his stead, Michael D. McCreary is E Ink's vice president of research and development. At the firm's offices in an office park on the outskirts of Cambridge, he explains that in the company's business plan, store signs were always considered a first step in proving the viability of electronic ink. "Our next step is developing high-resolution displays for portable devices," McCreary says. He shows a rigid, Palm Pilot–style screen (with better contrast, at 80-dpi resolution) that's viewable at wider angles than the standard black-and-white liquid-crystal display (LCD) on a handheld computer.

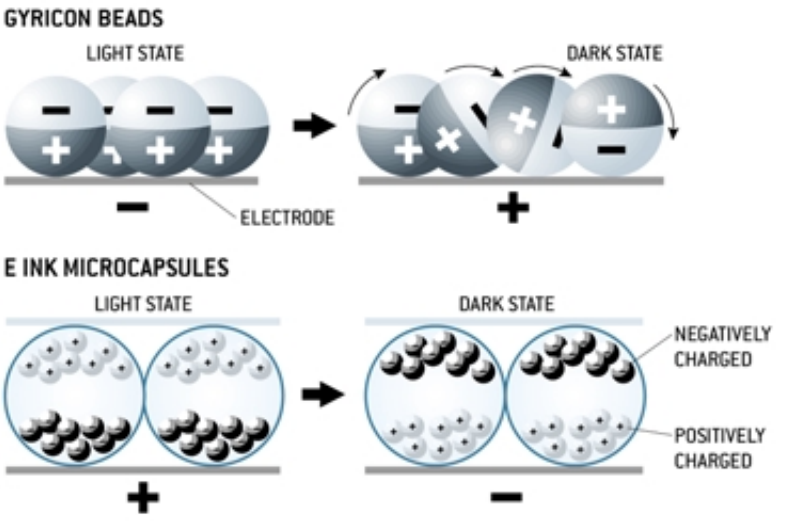
In February, Philips Components, a division of Royal Philips Electronics in the Netherlands, secured exclusive global rights for a period of time to manufacture and sell display modules using E Ink technology for personal digital assistants (PDAs) and electronic books in exchange for a $7.5-million investment in the company. With this version of electronic paper drawing as little as one hundredth the power of a comparable LCD screen, Philips is banking on a competitive advantage in battery life for its handheld devices, which will be available within the next two years.

Another corporate partner, Lucent Technologies, licensed its Bell Labs–developed plastic transistor technology to E Ink, while also investing in the company. In November 2000 this alliance demonstrated the first flexible electronic-ink display—a five-by-five-inch screen with the consistency and thickness of a computer mouse pad and just 256 cornflake-size pixels, which cycled through checkerboard patterns, the companies' names and the E Ink corporate logo. This demo was a proof-of-concept that the active-matrix circuitry for addressing E Ink's microcapsules could be fabricated with plastic materials rubber-stamped onto a flexible sheet of plastic.

By April, E Ink and yet another partner, IBM Research, had announced their first higher-resolution active-matrix electronic-ink display—a 12.1-inch-diagonal screen with a resolution comparable to 83 dpi, or about the same sharpness as a typi-

HOW E-PAPER WORKS

Both technologies being developed commercially for electronically configurable paperlike displays rely on microscopic beads that change color in response to the charges on nearby electrodes. Gyricon Media's SmartPaper uses two-tone solid beads that twist around in place (*top*). Inventor Nicholas K. Sheridon's breakthrough for producing tiny symmetrical beads involved pouring black and white resins onto a rapidly spinning disk. E Ink's Electronic Ink employs see-through microcapsules containing pigment chips that move through a liquid medium (*bottom*). Manufacturing applies standard techniques developed for microencapsulated coatings on business forms.



LAURIE GRACE

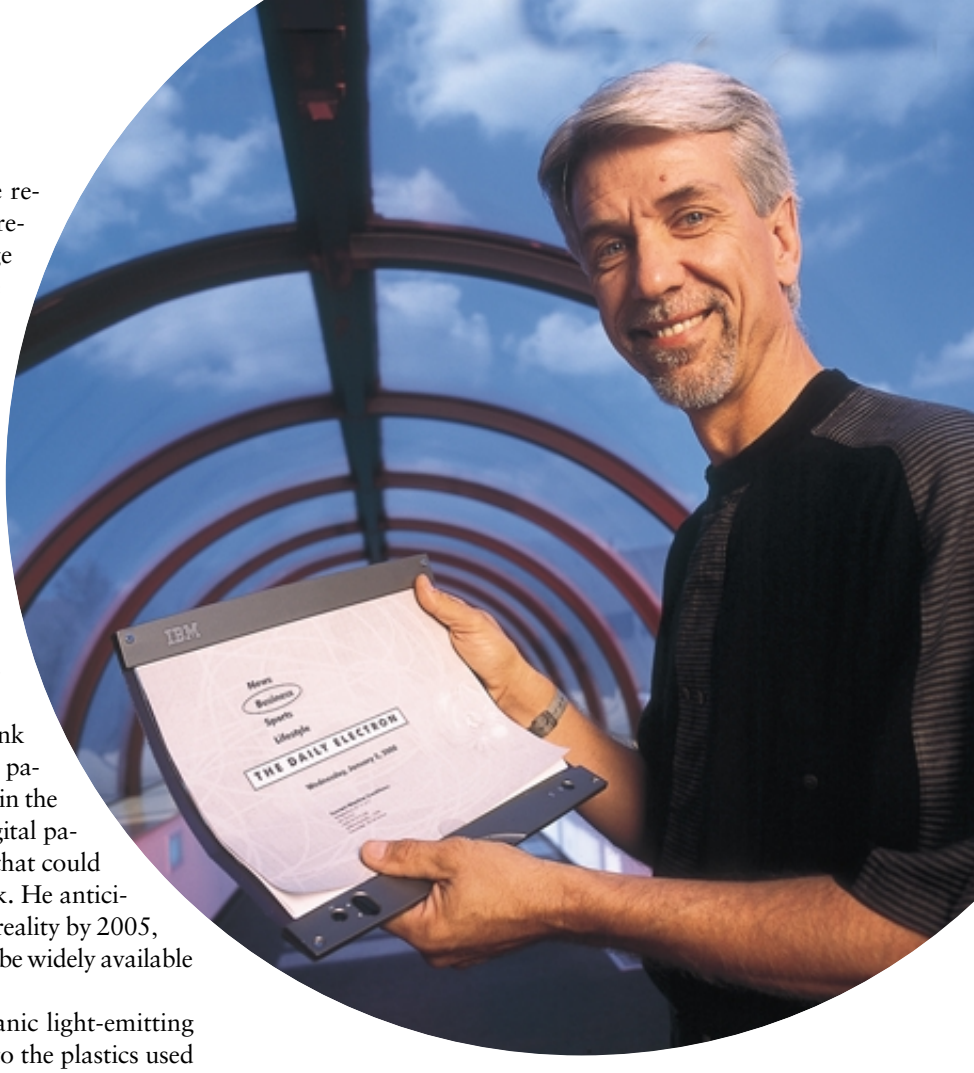
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cal laptop computer screen. To match the requirement of IBM's electronics, E Ink researchers made their microcapsules change color 10 times faster than they did in the original formulation. For better contrast, the encapsulated dye's color was changed from blue to deep black.

In May, E Ink and Japan's Toppan Printing Company introduced a prototype color electronic-ink display. Using Toppan's color filter arrays, which are now widely deployed in standard LCDs, the demonstration screen showed eight colors. Using this technology, E Ink expects to produce displays capable of showing 4,096 colors, comparable to handheld computer and game screens.

These recent prototypes have brought E Ink closer to its ultimate goal. "We call it 'radio paper,'" McCreary explains of the third stage in the E Ink business plan. This will be flexible digital paper with high-resolution-color capabilities that could be reconfigured via a wireless data network. He anticipates that radio paper will be a commercial reality by 2005, at which point similar technologies may also be widely available from Gyricon and other sources.

E Ink will also be competing with organic light-emitting diodes. Carbon-based compounds similar to the plastics used in E Ink and Lucent's flexible display can produce light-emitting semiconductors that are also pliable and relatively energy-efficient. That this alternative to electronic paper is being developed by Eastman Kodak, IBM and other well-financed firms should soon make this technology a credible challenger.



ROBERT STEINBUGLER, head of IBM's corporate strategic design program, shows a rubberized, flexible portfolio-style display concept with eight two-sided pages made of digital paper. The eNewspaper combines the familiar experience of flipping pages with the convenience of instantly rewritable text.

The Last Book

ALMOST FROM THE BEGINNING, Jacobson's long-term vision for e-ink has included "the last book": several hundred bound pages of self-printing paper with a separate processor imprinted on each page and enough memory chips in the hardcover volume's spine to store the entire contents of the Library of Congress. With a single page of e-inked paper able to replicate any stored page of text, graphics or even video, why bother binding together so many pages? According to Jacobson, one reason is to engage a reader's spatial memory: thumbing through a book-length work makes it easier to locate a particular passage or illustration.

Somewhere between Jacobson's e-tome and Sheridon's e-scroll, there's another format that electronic paper publishing could adopt. This one is an updated variation on early printing's folios—binary multiples (8, 16 or 32) of pages cut from a single large printed sheet. In 1999 Robert Steinbugler, head of IBM's corporate strategic design program, unveiled a design prototype for the eNewspaper—a rubberized, flexible, portfolio-style display device containing eight two-sided pages made of digital paper (actually plastic mock-ups, for now). Based on interviews with newspaper publishers and readers, Steinbugler concluded that a sheaf of pages afforded the ability to flip back and forth among stories without having to redraw their text, while also offering the serendipitous juxtaposition of stories that still distinguishes newspapers in print from their online, one-screen-at-a-time versions.

Given today's accelerated quest for electronic paper, it may not be too long before *Scientific American* readers are offered a choice of e-folio, e-hardcover or e-papyrus editions. SA

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MORE TO EXPLORE

Information about Electronic Reusable Paper is available on the Xerox PARC Web site at **www.parc.xerox.com/dhl/projects/gyricon/**

Information about SmartPaper is available on the Gyricon Media Web site at **www.gyriconmedia.com/smartpaper/index.asp**

What Is Electronic Ink? Available on the E Ink Web site at **www.eink.com/technology/index.htm**

The Last Book. Joseph Jacobson in *IBM Systems Journal,* Vol. 36, No. 3; 1997. Available at **www.research.ibm.com/journal/sj/363/jacobson.html**

SAM OGDEN

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The antiviral era is upon us, with an array of virus-fighting drugs on the market and in development. Research into viral genomes is fueling much of this progress

By William A. Haseltine

BEYOND CHICKEN SOUP

Back in the mid-1980s, when scientists first learned that a virus caused a relentless

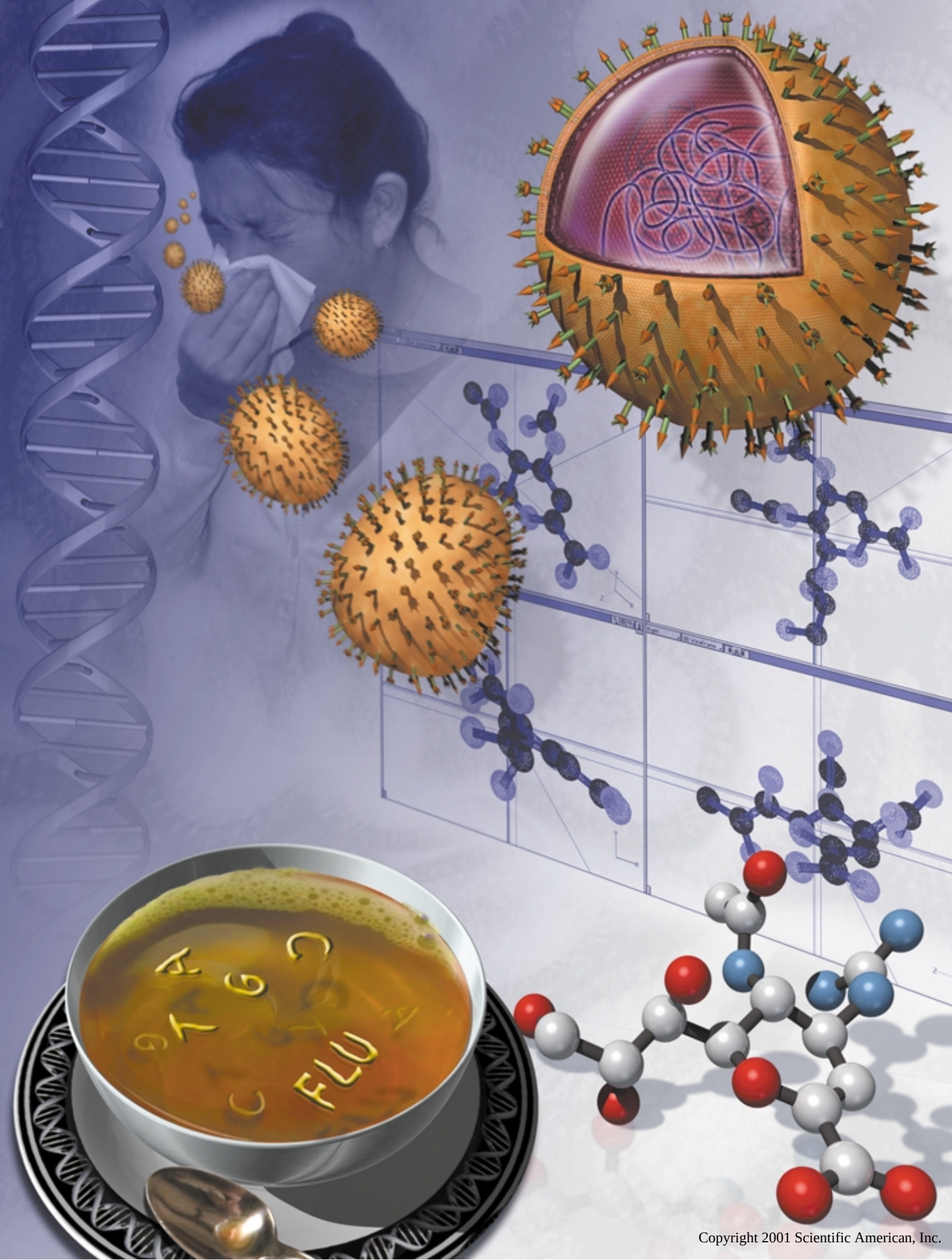
new disease named AIDS, pharmacy shelves were loaded with drugs able to treat bacterial infections. For viral diseases, though, medicine had little to offer beyond chicken soup and a cluster of vaccines. The story is dramatically different today. Dozens of antiviral therapies, including several new vaccines, are available, and hundreds more are in development. If the 1950s were the golden age of antibiotics, we are now in the early years of the golden age of antivirals.

This richness springs from various sources. Pharmaceutical companies would certainly point to the advent in the past 15 years of sophisticated techniques for discovering all manner of drugs. At the same time, frantic efforts to find lifesaving therapies for HIV, the cause of AIDS, have suggested creative ways to fight not only HIV but other viruses, too.

A little-recognized but more important force has also been at work: viral genomics, which deciphers the sequence of "letters," or nucleic acids, in a virus's genetic "text." This sequence includes the letters in all the virus's genes, which form the blueprints for viral proteins; these proteins, in turn, serve as the structural elements and the working

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parts of the virus and thus control its behavior. With a full or even a partial genome sequence in hand, scientists can quickly learn many details of how a virus causes disease—and which stages of the process might be particularly vulnerable to attack. In 2001 the full genome of any virus can be sequenced within days, making it possible to spot that virus's weaknesses with unprecedented speed.

The majority of antivirals on sale these days take aim at HIV, herpesviruses (responsible for a range of ills, from cold sores to encephalitis), and hepatitis B and C viruses (both of which can cause liver cancer). HIV and these forms of hepatitis will surely remain a main focus of investigation for some time; together they cause more than 250,000 cases of disease in the U.S. every year and millions in other countries. Biologists, however, are working aggressively to combat other viral illnesses as well. I cannot begin to describe all the classes of antivirals on the market and under study, but I do hope this article will offer a sense of the extraordinary advances that genomics and other sophisticated technologies have made possible in recent years.

Genomics has been a springboard for the development of whole new classes of antiviral drugs.

Drug-Search Strategies

THE EARLIEST ANTIVIRALS (mainly against herpes) were introduced in the 1960s and emerged from traditional drug-discovery methods. Viruses are structurally simple, essentially consisting of genes and perhaps some enzymes (biological catalysts) encased in a protein capsule and sometimes also in a lipid envelope. Because this design requires viruses to replicate inside cells, investigators infected cells, grew them in culture and exposed the cultures to chemicals that might plausibly inhibit viral activities known at the time. Chemicals that reduced the amount of virus in the culture were considered for in-depth investigation. Beyond being a rather hit-or-miss process, such screening left scientists with few clues to other viral activities worth attacking. This handicap hampered efforts to develop drugs that were more effective or had fewer side effects.

Genomics has been a springboard for discovering fresh targets for attack and has thus opened the way to development of whole new classes of antiviral drugs. Most viral targets selected since the 1980s have been identified with the help of genomics, even though the term itself was only coined in the late 1980s, well after some of the currently available antiviral drugs were developed.

After investigators decipher the sequence of code letters in a given virus, they can enlist computers to compare that sequence with those already identified in other organisms, including other viruses, and thereby learn how the sequence is segmented into genes. Strings of code letters that closely resemble known genes in other organisms are likely to constitute genes in the virus as well and to give rise to proteins that have similar structures. Having located a virus's genes, scientists can study the functions of the corresponding proteins and thus build a comprehensive picture of the molecular steps by which the virus of interest gains a foothold and thrives in the body.

That picture, in turn, can highlight the proteins—and the domains within those proteins—that would be good to disable. In general, investigators favor targets whose disruption would impair viral activity most. They also like to focus on protein domains that bear little resemblance to those in humans, to avoid harming healthy cells and causing intolerable side effects. They take aim, too, at protein domains that are basically identical in all major strains of the virus, so that the drug will be useful against the broadest possible range of viral variants.

After researchers identify a viral target, they can enlist various techniques to find drugs that are able to perturb it. Drug sleuths can, for example, take advantage of standard genetic engineering (introduced in the 1970s) to produce pure copies of a selected protein for use in drug development. They insert the corresponding gene into bacteria or other types of cells, which synthesize endless copies of the encoded protein. The resulting protein molecules can then form the basis of rapid screening tests: only substances that bind to them are pursued further.

Alternatively, investigators might analyze the three-dimensional structure of a protein domain and then design drugs that bind tightly to that region. For instance, they might construct a compound that inhibits the active site of an enzyme crucial to viral reproduction. Drug-

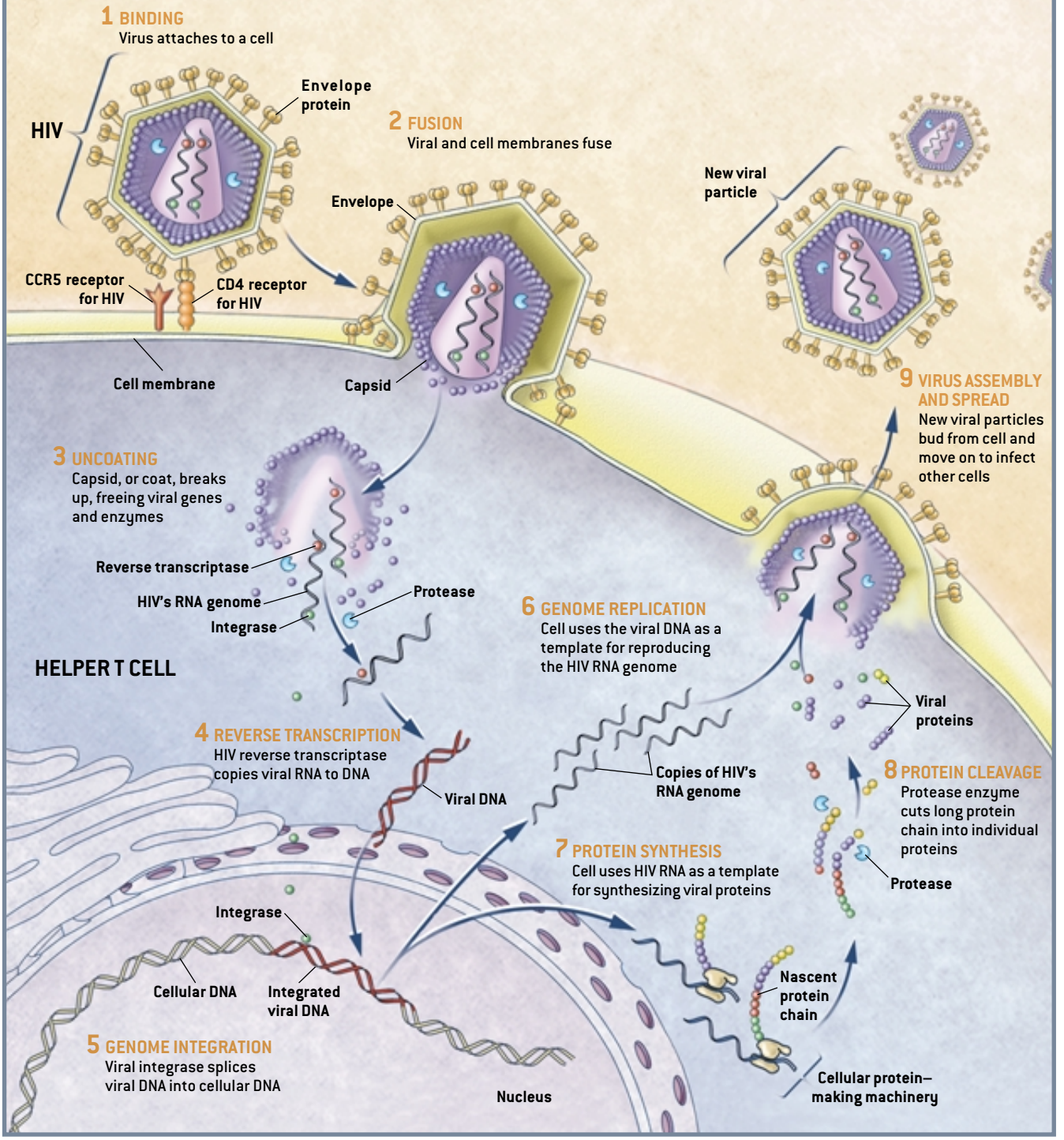
Overview/*Antiviral Drugs*

- Deciphering the genetic sequences, or genomes, of humans and of a variety of viruses has enabled scientists to devise drugs for diseases such AIDS, hepatitis and influenza.
- After decoding the genetic sequence of a virus, researchers can use computers to compare its sequence with those of other viruses—a process known loosely as genomics. The comparison allows drugmakers to identify genes in the new virus that encode molecules worth targeting.
- Viruses have complex life cycles but are vulnerable to attack by pharmaceuticals at nearly every stage.

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A VIRUS IN ACTION

HIV LIFE CYCLE, deciphered with the help of genomic analyses, is unusually complex in its details, but all viruses undergo the same basic steps to infect cells and reproduce. They enter a cell (bind to it and inject their genes into the interior), copy their genes and proteins (by co-opting the cell's machinery and raw materials), and pack the fresh copies into new viral particles able to spread to and infect other cells. The viral components involved in any of these steps can serve as targets for drugs, as the table on page 61 demonstrates.



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makers can also combine old-fashioned screening methods with the newer methods based on structures.

Advanced approaches to drug discovery have generated ideas for thwarting viruses at all stages of their life cycles. Viral species vary in the fine details of their reproductive strategies. In general, though, the stages of viral replication include attachment to the cells of a host, release of viral genes into the cells' interiors, replication of all viral genes and proteins (with help from the cells' own protein-making machinery), joining of the components into hordes of viral particles, and escape of those particles to begin the cycle again in other cells.

The ideal time to ambush a virus is in the earliest stage of an infection, before it has had time to spread throughout the body and cause symptoms. Vaccines prove their worth at that point, because they prime a person's immune system to specifically destroy a chosen disease-causing agent, or pathogen, almost as soon as it enters the body. Historically vaccines have achieved this priming by exposing a person to a killed or weakened version of the infectious agent that cannot make enough copies of itself to cause disease. So-called subunit vaccines are the most common alternative to these. They contain mere fragments of a pathogen; fragments alone have no way to produce an infection but, if selected carefully, can evoke a protective immune response.

An early subunit vaccine, for hepatitis B, was made by isolating the virus from the plasma (the fluid component of blood) of people who were infected and then purifying the desired proteins. Today a subunit hepatitis B vaccine is made by genetic engineering. Scientists use the gene for a specific hepatitis B protein to manufacture pure copies of the protein. Additional vaccines developed with the help of genomics are in development for other important viral diseases, among them dengue fever, genital herpes and the often fatal hemorrhagic fever caused by the Ebola virus.

Several vaccines are being investigated for preventing or treating HIV. But HIV's genes mutate rapidly, giving rise to many viral strains; hence, a vaccine that induces a reaction against certain strains might have no effect against others. By comparing the genomes of the various HIV strains, researchers can find sequences that are present in most of them and then use those sequences to produce purified viral protein fragments. These can be tested for their ability to induce immune protection against strains found worldwide. Or vaccines might be tailored to the HIV variants prominent in particular regions.

Bar Entry

TREATMENTS BECOME important when a vaccine is not available or not effective. Antiviral treatments effect cures for some patients, but so far most of them tend to reduce the severity or duration of a viral infection. One group of therapies limits viral activity by interfering with entry into a favored cell type.

The term "entry" actually covers a few steps, beginning with the binding of the virus to some docking site, or receptor, on a host cell and ending with "uncoating" inside the cell; during uncoating, the protein capsule (capsid) breaks up, releasing the virus's genes. Entry for enveloped viruses requires an extra step. Before uncoating can occur, these microorganisms must fuse their envelope with the cell membrane or with the membrane of a vesicle that draws the virus into the cell's interior.

Developers are also selecting novel drugs based on their ability to combat viral strains that are resistant to other drugs.

Several entry-inhibiting drugs in development attempt to block HIV from penetrating cells. Close examination of the way HIV interacts with its favorite hosts (white blood cells called helper T cells) has indicated that it docks with molecules on those cells called CD4 and CCR5. Although blocking CD4 has failed to prevent HIV from entering cells, blocking CCR5 may yet do so.

Amantidine and rimantidine, the first two (of four) influenza drugs to be introduced, interrupt other parts of the entry process. Drugmakers found the compounds by screening likely chemicals for their overall ability to interfere with viral replication, but they have since learned more specifically that the compounds probably act by inhibiting fusion and uncoating. Fusion inhibitors discovered with the aid of genomic information are also being pursued against respiratory syncytial virus (a cause of lung disease in infants born prematurely), hepatitis B and C, and HIV.

Many colds could soon be controlled by another entry blocker, pleconaril, which is reportedly close to receiving federal approval. Genomic and structural comparisons have shown that a pocket on the surface of rhinoviruses (responsible for most colds) is similar in most

THE AUTHOR

WILLIAM A. HASELTINE, who has a doctorate in biophysics from Harvard University, is the chairman of the board of directors and chief executive officer of Human Genome Sciences; he is also editor in chief of a new publication, the *Journal of Regenerative Medicine,* and serves on the editorial boards of several other scientific journals. He was a professor at the Dana-Farber Cancer Institute, an affiliate of Harvard Medical School, and at the Harvard School of Public Health from 1988 to 1995. His laboratory was the first to assemble the sequence of the AIDS virus genome. Since 1981 he has helped found more than 20 biotechnology companies.

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Antiviral Drugs Today

Sampling of antiviral drugs on the market appears below. Many owe their existence, at least in part, to viral genomics. About 30 other viral drugs based on an understanding of viral genomics are in human tests.

DRUG NAMES	SPECIFIC ROLES	MAIN VIRAL DISEASES TARGETED
	DISRUPTORS OF GENOME	
abacavir, didanosine, stavudine, zalcitabine, zidovudine	Nucleoside analogue inhibitors of reverse transcriptase	HIV infection
acyclovir, ganciclovir, penciclovir	Nucleoside analogue inhibitors of the enzyme that duplicates viral DNA	Herpes infections; retinal inflammation caused by cytomegalovirus
cidofovir	Nucleotide analogue inhibitor of the enzyme that duplicates viral DNA	Retinal inflammation caused by cytomegalovirus
delavardine, efavirenz	Nonnucleoside, nonnucleotide inhibitors of reverse transcriptase	HIV infection
lamivudine	Nucleoside analogue inhibitor of reverse transcriptase	HIV, hepatitis B infections
ribavirin	Synthetic nucleoside that induces mutations in viral genes	Hepatitis C infection
	DISRUPTORS OF PROTEIN SYNTHESIS	
amprenavir, indinavir, lopinavir, nelfinavir, ritonavir, saquinavir	Inhibitors of HIV protease	HIV infection
fomivirsen	Antisense molecule that blocks translation of viral RNA	Retinal inflammation caused by cytomegalovirus
interferon alpha	Activator of intracellular immune defenses that block viral protein synthesis	Hepatitis B and C infections
	BLOCKERS OF VIRAL SPREAD FROM CELL TO CELL	
oseltamivir, zanamivir	Inhibitors of viral release	Influenza
palivizumab	Humanized monoclonal antibody that marks virus for destruction	Respiratory syncytial infection

variants. Pleconaril binds to this pocket in a way that inhibits the uncoating of the virus. The drug also appears to be active against enteroviruses, which can cause diarrhea, meningitis, conjunctivitis and encephalitis.

Jam the Copier

A NUMBER OF ANTIVIRALS on sale and under study operate after uncoating, when the viral genome, which can take the form of DNA or RNA, is freed for copying and directing the production of viral proteins. Several of the agents that inhibit genome replication are nucleoside or nucleotide analogues, which resemble the building blocks of genes. The enzymes that copy viral DNA or RNA incorporate these mimics into the nascent strands. Then the mimics prevent the enzyme from adding any further building blocks, effectively aborting viral replication.

Acyclovir, the earliest antiviral proved to be both effective and relatively nontoxic, is a nucleoside analogue that was discovered by screening selected compounds for their ability to interfere with the replication of herpes simplex virus. It is prescribed mainly for genital herpes, but chemical relatives have value against other herpesvirus infections, such as shingles caused by varicella zoster and inflammation of the retina caused by cytomegalovirus.

The first drug approved for use against HIV, zidovudine (AZT), is a nucleoside analogue as well. Initially developed as an anticancer drug, it was shown to interfere with the activity of reverse transcriptase, an enzyme that HIV uses to copy its RNA genome into DNA. If this copying step is successful, other HIV enzymes splice the DNA into the chromosomes of an invaded cell, where the integrated DNA directs viral reproduction.

AZT can cause severe side effects, such as anemia. But studies of reverse transcriptase, informed by knowledge of the enzyme's gene sequence, have enabled drug developers to introduce less toxic nucleoside analogues. One of these, lamivudine, has also been approved for hepatitis B, which uses reverse transcriptase to convert RNA copies of its DNA genome back into DNA. Intense analyses of HIV reverse transcriptase have led as well to im-

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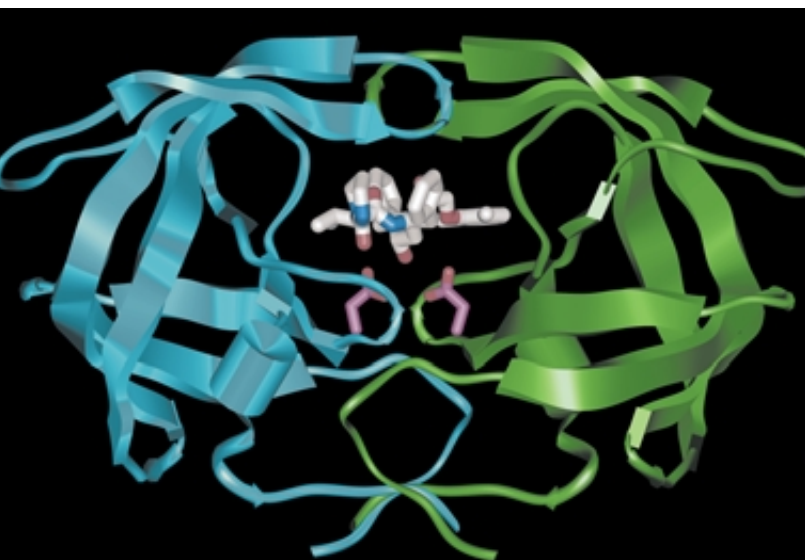
proved versions of a class of reverse transcriptase inhibitors that do not resemble nucleosides.

Genomics has uncovered additional targets that could be hit to interrupt replication of the HIV genome. Among these is RNase H, a part of reverse transcriptase that separates freshly minted HIV DNA from RNA. Another is the active site of integrase, an enzyme that splices DNA into the chromosomal DNA of the infected cell. An integrase inhibitor is now being tested in HIV-infected volunteers.

Impede Protein Production

ALL VIRUSES MUST at some point in their life cycle transcribe genes into mobile strands of messenger RNA, which the host cell then "translates," or uses as a guide for making the encoded proteins. Several drugs in development interfere with the transcription stage by preventing proteins known as transcription factors from attaching to viral DNA and switching on the production of messenger RNA.

Genomics helped to identify the targets for many of these agents. It also made possible a novel kind of drug: the antisense molecule. If genomic research shows that a particular protein is needed by a virus, workers can halt the protein's production by masking part of the corresponding RNA template with a custom-designed DNA fragment able to bind firmly to the selected RNA sequence. An antisense drug, fomivirsen, is already used to treat eye infections caused by cytomegalovirus in AIDS patients. And antisense agents are in development for other viral diseases; one of them blocks production of the HIV protein Tat, which is needed for the transcription of other HIV genes.



STRUCTURE OF HIV PROTEASE (*blue and green ribbons*) shows lopinavir—part of the AIDS drug Kaletra—binding to it. Such protease inhibitors prevent the virus from cleaving new viral proteins from a chain of many such proteins.

COURTESY OF ABBOTT LABORATORIES

Drugmakers have also used their knowledge of viral genomes to identify sites in viral RNA that are susceptible to cutting by ribozymes—enzymatic forms of RNA. A ribozyme is being tested in patients with hepatitis C, and ribozymes for HIV are in earlier stages of development. Some such projects employ gene therapy: specially designed genes are introduced into cells, which then produce the needed ribozymes. Other types of HIV gene therapy under study give rise to specialized antibodies that seek targets inside infected cells or to other proteins that latch onto certain viral gene sequences within those cells.

Some viruses produce a protein chain in a cell that must be spliced to yield functional proteins. HIV is among them, and an enzyme known as a protease performs this cutting. When analyses of the HIV genome pinpointed this activity, scientists began to consider the protease a drug target. With enormous help from computer-assisted structure-based research, potent protease inhibitors became available in the 1990s, and more are in development. The inhibitors that are available so far can cause disturbing side effects, such as the accumulation of fat in unusual places, but they nonetheless prolong overall health and life in many people when taken in combination with other HIV antivirals. A new generation of protease inhibitors is in the research pipeline.

Stop Traffic

EVEN IF VIRAL GENOMES and proteins are reproduced in a cell, they will be harmless unless they form new viral particles able to escape from the cell and migrate to other cells. The most recent influenza drugs, zanamivir and oseltamivir, act at this stage. A molecule called neuraminidase, which is found on the surface of both major types of influenza (A and B), has long been known to play a role in helping viral particles escape from the cells that produced them. Genomic comparisons revealed that the active site of neuraminidase is similar among various influenza strains, and structural studies enabled researchers to design compounds able to plug that site. The other flu drugs act only against type A.

Drugs can prevent the cell-to-cell spread of viruses in a different way—by augmenting a patient's immune responses. Some of these responses are nonspecific: the drugs may restrain the spread through the body of various kinds of invaders rather than homing in on a particular pathogen. Molecules called interferons take part in this type of immunity, inhibiting protein synthesis and other aspects of viral replication in infected cells. For that reason, one form of human interferon, interferon alpha, has been a mainstay of therapy for hepatitis B and C. (For hepatitis C, it is used with an older drug, ribavirin.) Other interferons are under study, too.

More specific immune responses include the production of standard antibodies, which recognize some fragment of a protein on the surface of a viral invader, bind to that protein and mark the virus for destruction by other parts of the immune system. Once researchers have the

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gene sequence encoding a viral surface protein, they can generate pure, or "monoclonal," antibodies to selected regions of the protein. One monoclonal is on the market for preventing respiratory syncytial virus in babies at risk for this infection; another is being tested in patients suffering from hepatitis B.

Comparisons of viral and human genomes have suggested yet another antiviral strategy. A number of viruses, it turns out, produce proteins that resemble molecules involved in the immune response. Moreover, certain of those viral mimics disrupt the immune onslaught and thus help the virus to evade destruction. Drugs able to intercept such evasion-enabling proteins may preserve full immune responses and speed the organism's recovery from numerous viral diseases. The hunt for such agents is under way.

The Resistance Demon

THE PACE OF ANTIVIRAL drug discovery is nothing short of breathtaking, but at the same time, drugmakers have to confront a hard reality: viruses are very likely to develop resistance, or insensitivity, to many drugs. Resistance is especially probable when the compounds are used for long periods, as they are in such chronic diseases as HIV and in quite a few cases of hepatitis B and C. Indeed, for every HIV drug in the present arsenal, some viral strain exists that is resistant to it and, often, to additional drugs. This resistance stems from the tendency of viruses—especially RNA viruses and most especially HIV—to mutate rapidly. When a mutation enables a viral strain to overcome some obstacle to reproduction (such as a drug), that strain will thrive in the face of the obstacle.

To keep the resistance demon at bay until effective vaccines are found, pharmaceutical companies will have to develop more drugs. When mutants resistant to a particular drug arise, reading their genetic text can indicate where the mutation lies in the viral genome and suggest how that mutation might alter the interaction between the affected viral protein and the drug. Armed with that information, researchers can begin structure-based or other studies designed to keep the drug working despite the mutation.

Pharmaceutical developers are also selecting novel drugs based on their ability to combat viral strains that are resistant to other drugs. Recently, for instance, DuPont Pharmaceuticals chose a new HIV nonnucleoside reverse transcriptase inhibitor, DPC 083, for development precisely because of its ability to overcome viral resistance to such inhibitors. The company's researchers first examined the mutations in the reverse transcriptase gene that conferred resistance. Next they turned to computer modeling to find drug designs likely to inhibit the reverse transcriptase enzyme in spite of those mutations. Then, using genetic engineering, they created viruses that produced the mutant enzymes and selected the compound best able to limit reproduction by those viruses. The drug is now being evaluated in HIV-infected patients.

Deciphered Viruses

Some medically important viruses whose genomes have been sequenced are listed below. Frederick Sanger of the University of Cambridge and his colleagues determined the DNA sequence of the first viral genome—from a virus that infects bacteria—in 1977.

VIRUS	DISEASE	YEAR SEQUENCED
Human poliovirus	Poliomyelitis	1981
Influenza A virus	Influenza	1981
Hepatitis B virus	Hepatitis B	1984
Human rhinovirus type 14	Common cold	1984
HIV-1	AIDS	1985
Human papillomavirus type 16	Cervical cancer	1985
Dengue virus type 1	Dengue fever	1987
Hepatitis A virus	Hepatitis A	1987
Herpes simplex virus type 1	Cold sores	1988
Hepatitis C virus	Hepatitis C	1990
Cytomegalovirus	Retinal infections in HIV-infected people	1991
Variola virus	Smallpox	1992
Ebola virus	Ebola hemorrhagic fever	1993
Respiratory syncytial virus	Childhood respiratory infections	1996
Human parainfluenzavirus 3	Childhood respiratory infections	1998

It may be some time before virtually all serious viral infections are either preventable by vaccines or treatable by some effective drug therapy. But now that the sequence of the human genome is available in draft form, drug designers will identify a number of previously undiscovered proteins that stimulate the production of antiviral antibodies or that energize other parts of the immune system against viruses. I fully expect these discoveries to translate into yet more antivirals. The insights gleaned from the human genome, viral genomes and other advanced drug-discovery methods are sure to provide a flood of needed antivirals within the next 10 to 20 years. SA

MORE TO EXPLORE

Viral Strategies of Immune Evasion. Hidde L. Ploegh in *Science,* Vol. 280, No. 5361, pages 248–253; April 10, 1998.

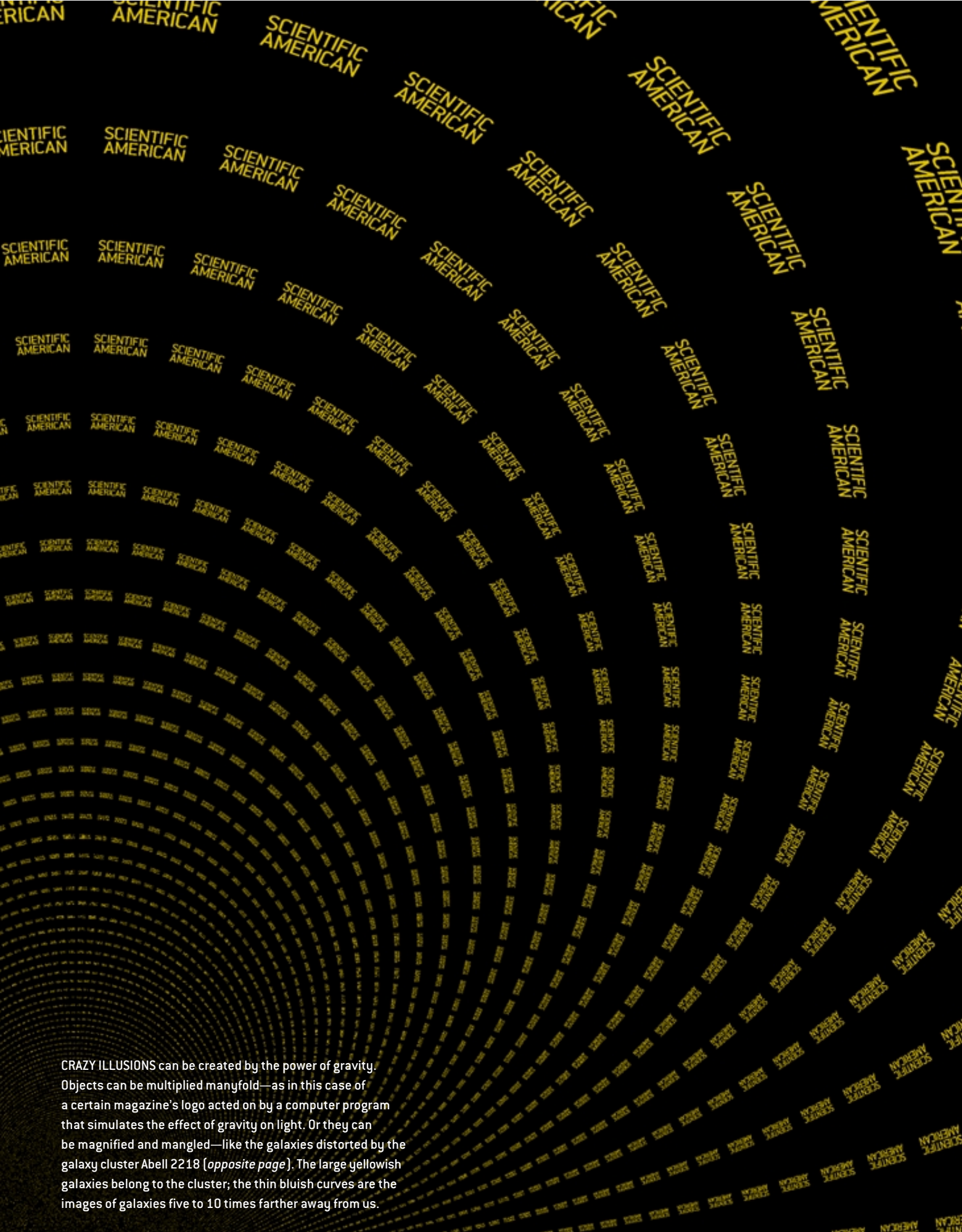
Strategies for Antiviral Drug Discovery. Philip S. Jones in *Antiviral Chemistry and Chemotherapy,* Vol. 9, No. 4, pages 283–302; July 1998.

New Technologies for Making Vaccines. Ronald W. Ellis in *Vaccine,* Vol. 17, No. 13-14, pages 1596–1604; March 26, 1999.

Protein Design of an HIV-1 Entry Inhibitor. Michael J. Root, Michael S. Kay and Peter S. Kim in *Science,* Vol. 291, No. 5505, pages 884–888; February 2, 2001.

Antiviral Chemotherapy: General Overview. Jack M. Bernstein, Wright State University School of Medicine, Division of Infectious Diseases, 2000. Available at **www.med.wright.edu/im/AntiviralChemotherapy.html**

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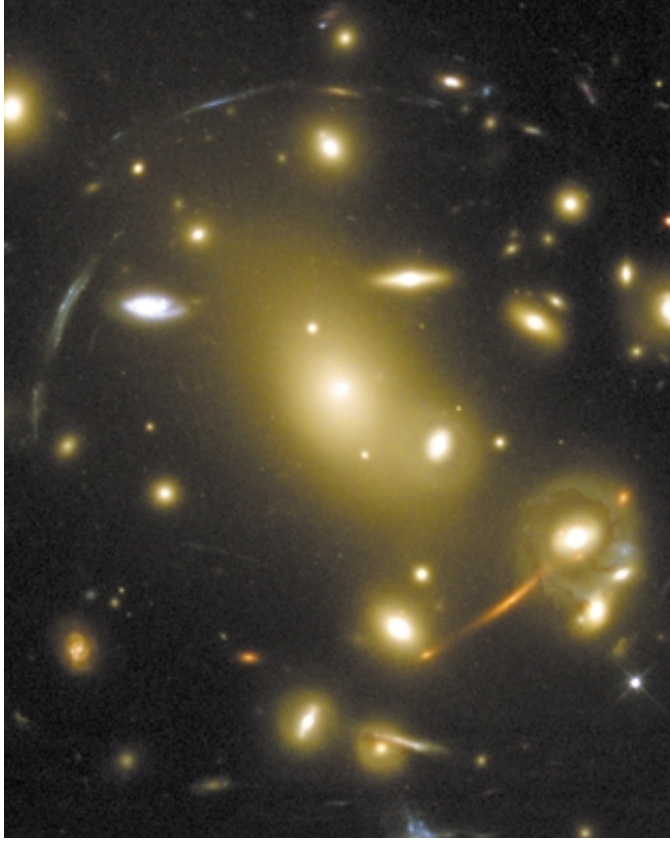


CRAZY ILLUSIONS can be created by the power of gravity. Objects can be multiplied manyfold—as in this case of a certain magazine's logo acted on by a computer program that simulates the effect of gravity on light. Or they can be magnified and mangled—like the galaxies distorted by the galaxy cluster Abell 2218 (*opposite page*). The large yellowish galaxies belong to the cluster; the thin bluish curves are the images of galaxies five to 10 times farther away from us.

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The most massive telescopes known to humanity sit not on earthly mountaintops but in deep space. They are gravitational lenses, once mere curiosities, now one of the most important tools in astronomy

By Joachim Wambsganss



Gravity's Kaleidoscope

MARK CLEMENS, USING ADOBE PHOTOSHOP; GRAVITATIONAL LENS FILTER BY PETE KERNAN *Case Western Reserve University (theory2.phys.cwru.edu/~pete) (opposite);* ANDREW FRUCHTER *Space Telescope Science Institute and NASA (Abell 2218)*

To many people, the universe seems like a hall of mirrors—filled with objects that are beyond bizarre and phenomena that challenge our very understanding of reality. Little do they realize how apt this metaphor is. The skies are riddled with fun-house illusions: quasars that appear in quadruplicate, galaxies that are squished from their usual pinwheel or beehive shape into long, skinny threads, stars that fade in and out like streetlamps on a foggy night. Just as psychologists prize optical illusions for what they reveal about the brain, astronomers find that the heavenly mirages show a universe they might not otherwise see.

Usually light from an astronomical object goes straight from the object through the depths of space into our telescopes. But if a second object is located exactly in between, its gravity can deflect the light, much as a glass lens does. We see a distorted, magnified or multiplied image. Analysis of that image can shed light both on the background object and on the lens itself.

The study of gravitational lensing is still a young field, having just finished its teenage years as an observational science. A decade or so ago astronomers knew of just a few examples of lenses [see "Gravitational Lenses," by Edwin L. Turner; SCIENTIFIC AMERICAN, July 1988]. They have since detected and explored entire new manifestations of lensing: the so-called microlensing of quasars and stars; arclets and weak lensing in galaxy clusters; and, last year, the subtle shearing caused by very weak lensing of the large-scale structure of the universe. Anything that possesses mass can serve as a lens; it does not need to emit light of its own. For this reason, gravitational lensing is one of the few ways that astronomers can map out the invisible dark matter of the universe. Lensing can also probe the internal structure of quasars, spot black holes traipsing through interstellar space and detect Earth-mass planets around other stars.

Credit for gravitational lensing is often given to Albert Einstein, but he was not, in fact, the first person to predict it. As early as 1801, Berlin astronomer and geographer Johann Georg von Soldner argued that the attractive force of the sun could

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bend the light rays of distant stars. According to Newtonian gravity theory, the position of a star seen near the edge of the sun should shift by 0.84 arcsecond relative to its position measured half a year later, when the sun is elsewhere in the sky.

According to general relativity, however, the angle is twice as large. As Einstein wrote, "Half of this deflection is produced by the Newtonian field of attraction of the sun, and the other half by the geometrical modification ('curvature') of space caused by the sun." During the now famous solar eclipse of May 1919, British astrophysicists Arthur S. Eddington and Frank W. Dyson measured this effect and confirmed the relativistic estimate (although, in retrospect, the experimental precision was probably insufficient to distinguish the two estimates beyond a reasonable doubt).

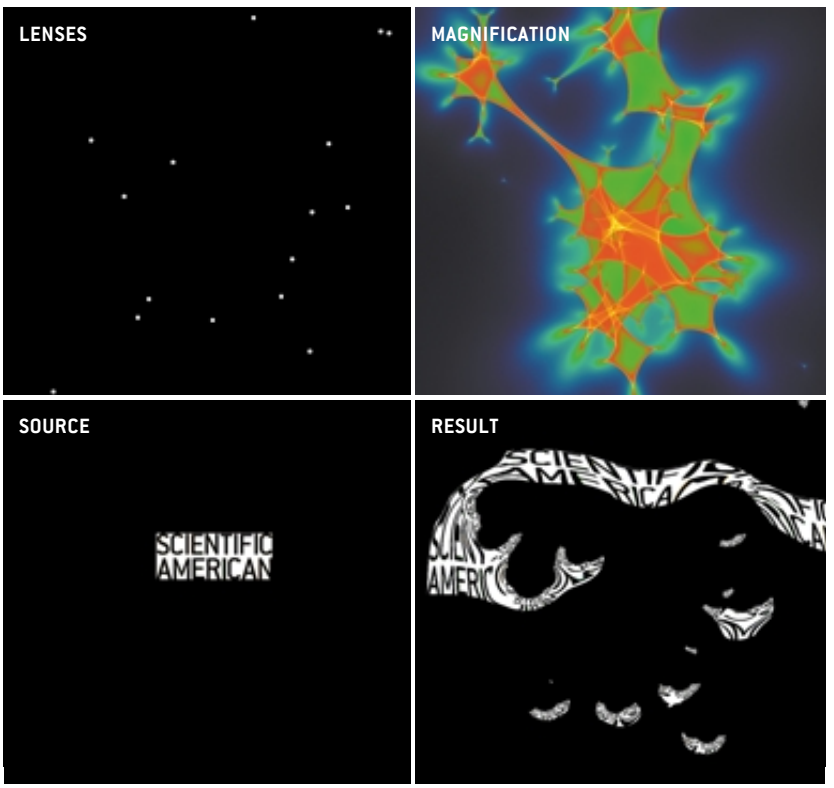
Einstein dealt again with gravitational light deflection in the 1930s, when he predicted that a foreground star could magnify the image of a background star. But he was skeptical that such an illusion could ever be seen. More optimistic were Swiss-American astrophysicist Fritz Zwicky, who predicted the lensing effects of galaxies and galaxy clusters, and American Henry Norris Russell, who suggested that this light deflection could be used to visualize and popularize relativity [see "A Relativistic Eclipse," by Henry Norris Russell; SCIENTIFIC AMERICAN, February 1937]. It was not until 1979, however, that astronomers actually saw evidence of lensing. The following pages review the progress since then.

THE AUTHOR

JOACHIM WAMBSGANSS often compares gravitational lensing to looking through the bottom of a wineglass. Both produce the same type of distortion. But what makes the comparison so apt is that Wambsganss comes from a family of winemakers; his uncles, cousins and parents own vineyards in the Rhine Valley. He says he became interested in cosmology when a high school teacher gave him a copy of *Scientific American*. (No, we didn't bribe him to say that.) Today he is a physics professor at Potsdam University.

FOUR CONSEQUENCES OF GRAVITATIONAL LIGHT DEFLECTION

- CHANGE OF POSITION The deflection shifts the apparent location of a star, galaxy or quasar in the sky. In most cases, this makes little difference to observers, because they do not know where the object would have been in the absence of lensing. But if the source-lens alignment changes—for instance, if either is moving—astronomers can directly measure the displacement.
- MAGNIFICATION AND DEMAGNIFICATION The deflection and focusing of light rays affect the apparent brightness of the background star or quasar. Although most cosmic sources are demagnified slightly, some are magnified by varying degrees. Observers have measured magnifications of more than 100 times.
- DEFORMATION Extended cosmic objects (such as galaxies) often appear stretched along a circle centered on the lens, producing banana-shaped arcs. Point sources (such as stars and quasars, which are either too small or too distant to see in detail) typically remain points.
- MULTIPLICATION Strong gravitational lensing can produce multiple images. Additional images always emerge in pairs, and one of these images is mirror-inverted. Although the number of images must be odd, one image is usually obscured, so observers see an even number.



SIMULATED DISTORTION demonstrates the lensing effects of a cluster of stars (*top left*). Whenever a lens is not a single object but a collection of objects, the outcome can get rather complicated. Astronomers visualize this by preparing a color map (*top right*) that shows magnification as a function of position. The cluster magnifies a source of light to a small (*blue*), moderate (*green*) or large (*red*) degree. The yellow lines are so-called caustics, where the magnification is extremely high. The uneven magnification distorts a perfectly respectable magazine logo (*bottom left*) into a phantasmagoria (*bottom right*).

JOACHIM WAMBSGANSS

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1. How Lensing Works

Stars, galaxies or black holes can deflect light rays from the straight and narrow

A gravitational-lens system comprises four ingredients: a distant source of light (star, galaxy or quasar), an intervening mass that acts as the lens (anything from a planet to a black hole), an observer on Earth, and the space in which all three are embedded. The line that connects lens and observer is called the optical axis.

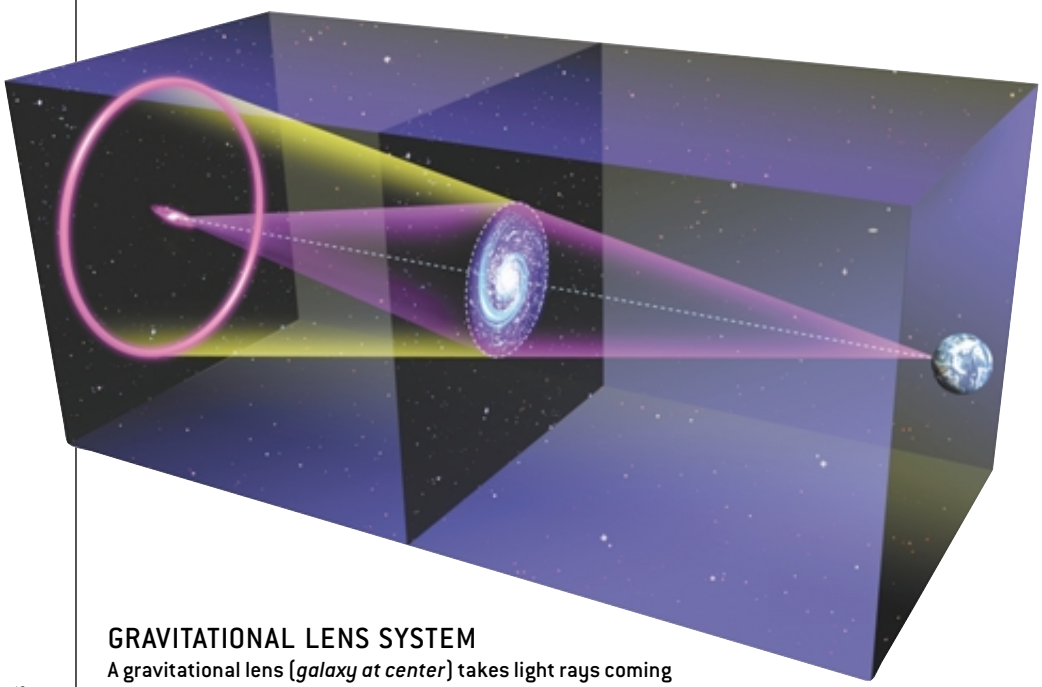
Light always follows the shortest possible route between two points. But Einstein showed that the shortest connection between two points can be curved, just as the shortest path between two points on the surface of Earth is part of a great circle. As light rays approach the curved space near a cosmic body, they will bend. The degree of deflection depends on how close the rays get to the body and how massive this body is. The deflection angle is directly proportional to the mass and inversely proportional to the closest distance.

In many ways, gravitational lenses act like ordinary glass lenses. One of the major differences is that ordinary lenses have a well-defined focal point, whereas the gravitational varieties produce focal lines or surfaces. The convex shape of an ordinary lens ensures that the deflection angle is directly proportional to the distance from the optical axis. All incoming parallel rays meet at the same point behind the lens—the focus. The typical gravitational lens, however, causes light rays to experience smaller deflections the farther they are from the optical axis. For this reason, parallel rays deflected by gravity meet at different locations behind the lens, depending on how far away from the optical axis they originate. Certain glass lenses have the same effect; a good example is the bottom of a wineglass.

Another difference between gravitational lenses and ordinary glass lenses is that the former affect all wavelengths of light equally. In other words, gravitational lensing is achromatic. For glass lenses, the degree of deflection depends on the wavelength of the light. Gravitational-lensing effects have been measured throughout the electromagnetic spectrum, even in x-rays, which cannot be focused by glass optics.

If the lens system is perfectly symmetric—source, lens and observer are in alignment, and the lens is a point or sphere—the rays converge somewhere along the optical axis and the resulting image is a ring (*below*). But if the system is asymmetric—if the alignment is slightly off or the lens has an oblong mass distribution—the ring breaks up into discrete variegated images. The lens magnifies different parts of the source by different amounts. The highest magnification occurs for parts of the source that happen to be on a curve known as the caustic. An everyday example of caustics is the lacework of bright lines you see on the bottom of a sunlit swimming pool; the ripples on the surface of the water act as irregular lenses.

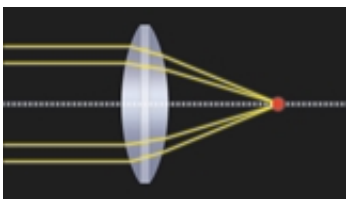
If the alignment is very far off or the lens mass distribution is very spread out, the lensing is weak. Images are barely distorted or magnified. Although in this case the effects are difficult to discern for a single object, they can often be detected statistically by looking at large populations of objects.



GRAVITATIONAL LENS SYSTEM

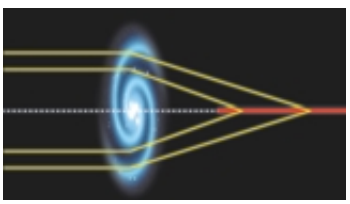
A gravitational lens (*galaxy at center*) takes light rays coming from a distant galaxy and focuses some of them (*purple cone*) on Earth. To observers, the light appears to have followed a straight line (*yellow cone*), giving the illusion that it emanated from a ring.

SLIM FILMS



CONVEX GLASS LENS

Light near the edge of a glass lens is deflected more than light near the optical axis. Thus, the lens focuses parallel light rays onto a point.



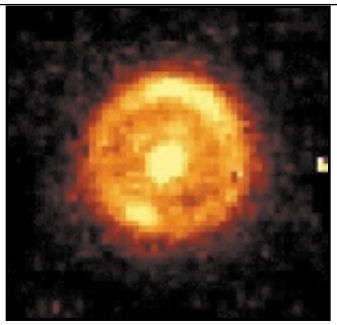
GRAVITATIONAL LENS

Light near the edge of a gravitational lens is deflected less than light near the center. Thus, the lens focuses light onto a line rather than a point.

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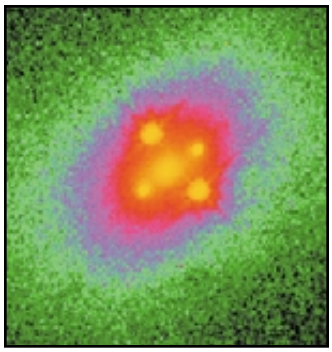
II. Quasars

As mighty as quasars are, they appear as mere dots in most telescopes. Gravitational lensing can peer inside them



EINSTEIN RING B1938+666

MULTIPLE QUASARS

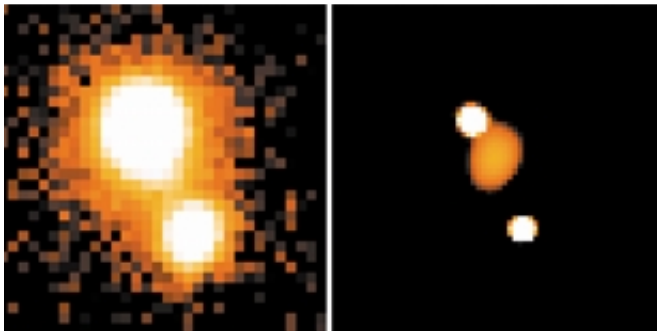


QUADRUPLE QUASAR Q2237+0305

Gravitational lensing became an observational science in 1979, when Dennis Walsh of Jodrell Bank Observatory in England and his colleagues discovered the double quasar Q0957+561, a pair of almost identical quasars right next to each other in the sky. Today astronomers know of 64 double, triple and multiple quasars separated by a few arcseconds or less. They are rare, accounting for roughly one out of every 500 observed quasars. The most comprehensive attempt so far to determine their prevalence was the CLASS (Cosmic Lens All-Sky Survey) project, which mapped more than 10,000 radio sources and found 17 multiply imaged systems.

To make sure a grouping is an illusion rather than a real cluster of quasars, observers go down a checklist: Do the quasars lie at the same distance, as determined by measuring the redshift? Are their spectra, which are as characteristic for quasars as fingerprints are for humans, identical or at least very similar? Is there a galaxy—a potential lens—between us and the quasar? Finally, does the brightness of each quasar fluctuate in exactly the same way?

The third of these criteria, the detection of a lens galaxy, is not rigid, because it is possible that the galaxy is either very faint or even completely dark. For instance, it may be a lump of gas in which no stars have formed. The lens may not even be a galaxy but rather an isolated black hole with a comparable mass. But in every well-studied case of multiple-quasar images, astronomers have been able to detect a more or less normal galaxy. One implication is that the universe does not contain large numbers of dark galaxies or isolated supermassive black holes.



DOUBLE QUASAR HE1104–1805, straddling a faint lensing galaxy

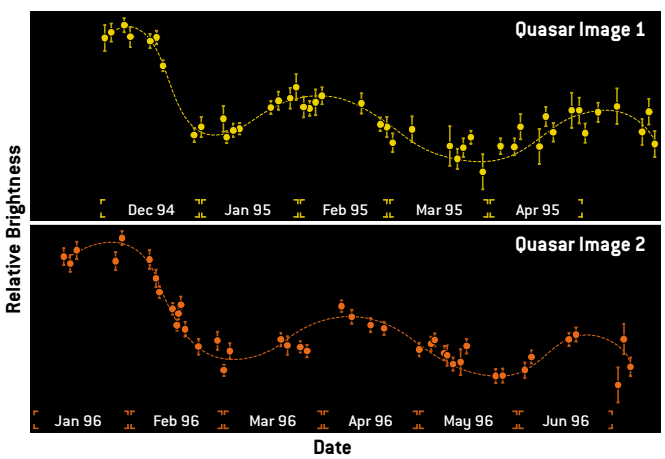
EINSTEIN RINGS

When a lens galaxy is spherically symmetric, it can redistribute the light of a background quasar or galaxy into a complete circle. The diameter of the ring is proportional to the square root of the lensing mass—providing a very elegant way of determining the mass of the lens galaxy. About a dozen Einstein rings are now known.

HUBBLE CONSTANT

One of the most powerful applications of quasar lensing, first suggested by Sjur Refsdal of Hamburg University in Germany in 1964, is to gauge the Hubble constant, a measure of the size and present expansion rate of the universe. Most other techniques to determine this value rely on a long ladder of distance measurements, but the gravitational-lens method leaps to the answer in a single bound.

When one of the images in a double quasar changes its brightness, the other one usually does, too—but not at exactly the same time. A delay is introduced by two effects: lensing asymmetry (which forces the light rays that produce each image to take paths of slightly different lengths) and the gravitational field of the lens (which, according to relativity theory, reduces the apparent velocity of light). From models of the shape and mass distribution of the lens, astronomers can estimate the time delay as a fraction of the total light-travel time. Then, by measuring the time delay and dividing by this fraction—typically about one ten-billionth—they can calculate the total light-travel time from the quasar, hence its distance. Because the redshift measures the receding speed, the constant of proportionality between



MATCHING BRIGHTNESS VARIATIONS of the double quasar Q0957+561

ROBERT SCHMIDT *University of Cambridge, SPACE TELESCOPE SCIENCE INSTITUTE AND NASA (quadruple quasar)*; LINDSAY KING *University of Bonn and CLASS Team (ring)*; SARA CHEN, SOURCE: TOMISLAV KUNDIĆ *Renaissance Technologies (graph)*; FREDERIC COURBIN *Pontificia Universidad Catolica, Chile (double quasar)*

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distance and velocity, the Hubble constant, can be calculated.

The technique was first applied to the double quasar Q0957+561 (*diagram on opposite page*). Flickers in one of the quasar images (*blue*) appear in the other (*red*) about 417 days later, which implies that the quasar is about 14 billion light-years away. Astronomers have now measured time delays from seven multiple-quasar systems. The inferred value of the Hubble constant is lowish but matches those arrived at by other techniques, within the error bars. The biggest uncertainty is the complicated mass distribution in the lenses.

COSMOLOGICAL CONSTANT

Multiple quasars can also give insight into another infamous cosmological parameter, the cosmological constant. This constant, or something like it, is needed to explain why the expansion of the universe appears to be accelerating [see "The Quintessential Universe," by Jeremiah P. Ostriker and Paul J. Steinhardt; SCIENTIFIC AMERICAN, January]. The acceleration relates to lensing because it makes the universe larger, which increases the probability that a quasar will be lensed. The more the expansion has accelerated, the bigger the volume of space and the more likely it is that an alignment between a galaxy and a distant quasar occurs (*below*). Therefore, the number of multiple quasars can put an upper bound on the cosmological constant.

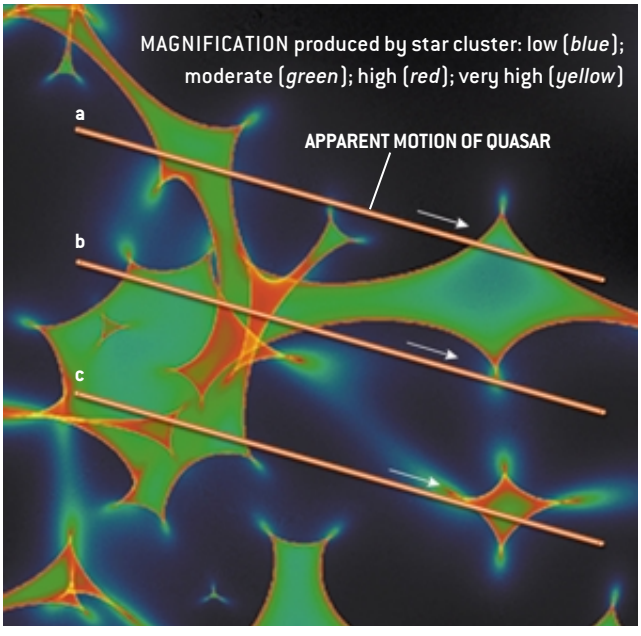
In 1998 Emilio E. Falco, Chris S. Kochanek and Jose A. Muñoz of the Harvard-Smithsonian Center for Astrophysics concluded that the cosmological constant cannot account for more than 62 percent of the energy density of the universe. If the constant were larger than this value, then observers should find many more multiple quasars than they do. This analysis favors smaller values of the constant than do such cosmological measurements as the brightness of distant supernovae, but the difference is not statistically significant, and more recent studies have loosened the constraint a bit.

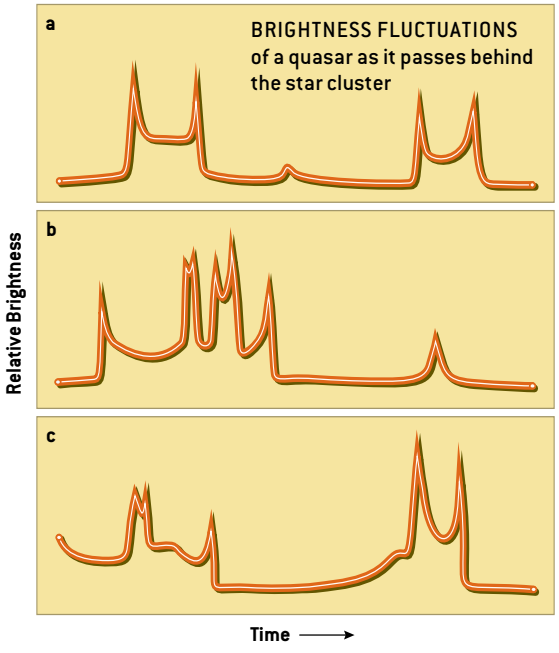
MICROLENSING OF QUASARS

Lensing is not always as obvious as in the examples above. If a star does the lensing, for example, the images are so close together that even the best telescopes cannot resolve them. This so-called microlensing effect is nonetheless measurable. Because the star is moving, the lens configuration—and therefore the magnification—changes over time. If observers see a quasar brighten and then dim in a particular way, they can infer that a star passed in front and briefly magnified its image.

The problem is that quasars are unsteady; they tend to brighten and dim on their own. To distinguish microlensing fluctuations from the quasar's intrinsic variability, astronomers monitor multiple-quasar systems. If one of the images flickers while the others do not, it may be because a star within the lens galaxy has passed into the line of sight and temporarily added an extra brightening to the effect already produced by the galaxy as a whole. Intrinsic changes, on the other hand, will show up in all the images. Since 1989 astronomers have confirmed microlensing in five multiple-quasar systems.

The brightness of the quasar increases smoothly until it hits a caustic, and then it undergoes an abrupt drop. The effect depends on the size of the quasar: the smaller it is, the more abruptly the brightness varies. These patterns provide a way to measure the size of the quasar and probe its internal structure. The brightness varies more abruptly in blue light than in red light. Consequently, researchers conclude that the innermost parts of a quasar are hotter and bluer than the outer parts. By monitoring caustic crossings using various color filters, astronomers can reconstruct the brightness profile of the quasar.





JOACHIM WAMBSGANSS (*color map*); SARA CHEN (*graph*)

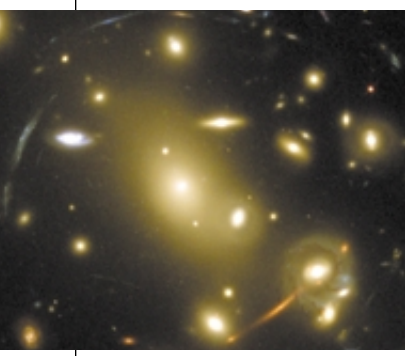
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III. Galaxies

The lensing of galaxies betrays the presence of dark matter

GIANT LUMINOUS ARCS

If the lens is not a single galaxy but an entire cluster of galaxies, the image can be a kaleidoscope of strongly distorted arcs and arclets. The first giant luminous arcs were discovered in 1986 independently by Roger Lynds of National Optical Astronomy Observatory with Vahé Petrosian of Stanford University and by Genevieve Soucail of Midi-Pyrénées Observatory in France and her colleagues. Almost 100 such arc clusters have been identified so far, one of the most dramatic being cluster Abell 2218 (*left*).

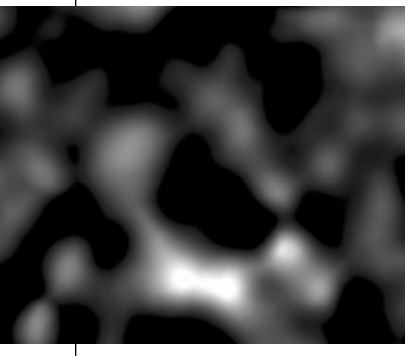


CLUSTER Abell 2218 distorts images of more distant galaxies.

With the help of these images, astronomers can reconstruct the mass distribution inside the cluster. The results, like those of other techniques for measuring cluster masses, imply that clusters are dominated by unseen dark matter. In addition, like multiple quasars, arcs can provide estimates of cosmological parameters such as the cosmological constant. In 1998 Matthias Bartelmann of the Max Planck Institute for Astrophysics in Garching, Germany, and his colleagues used the number of observed arc systems to measure the cosmological constant and came up with a lower value than have scientists using other methods. This discrepancy has not yet been resolved.

COSMIC SHEAR

On extremely large scales, vaster even than galaxy clusters, agglomerations of matter tend to be too broad and smooth to act as powerful lenses. Any distortion of galaxy images tends to get lost in the natural variation of galaxy shapes. But when astronomers analyze thousands of galaxies, they can use statistical methods to look for tiny but systematic distortions. Last year four teams—led by David J. Bacon of the University of Cambridge, Nick Kaiser of the University of Hawaii Institute for Astronomy, Ludovic van Waerbeke of the Canadian Institute for Theoretical Astrophysics and David M. Wittman of Lucent Technologies in Murray Hill, N.J.—independently discovered this very weak lensing effect. The widespread shearing of galaxy images supports the view that the universe is a giant cobweb of matter interspersed with voids.



RECONSTRUCTION of dark matter distribution using weak lensing

IV. Stars

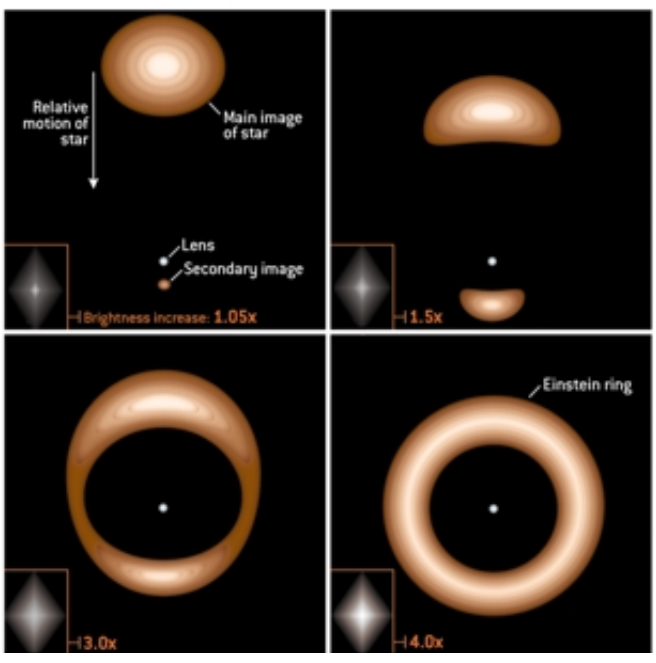
The distortion of stars is too subtle to see directly but shows up as a slow waxing and waning

MICROLENSING OF STARS

Lensing is an ideal way to ferret out the dark matter that lurks in the outermost part of our galaxy, the halo. Some of this dark matter may be exotic elementary particles, but some may comprise macroscopic objects that telescopes, for whatever reason, cannot see directly: rogue planets, dead stars or black holes. In 1986 Bohdan Paczyński of Princeton University suggested a technique to search for such objects, collectively known as MACHOs, or massive compact halo objects.

If a MACHO drifts in front of a background star, it will magnify that star and create a second image (*below*). Observers will not be able to resolve the images, but they will notice a temporary brightening. The duration of the event is proportional to the square root of the lens mass. This microlensing effect is relatively easy to distinguish from the other ways in which stars vary in brightness. At any given moment, the chance of such an alignment is only about one in a million. But if observers monitor millions of stars at a time, they should occasionally see a microlensing event.

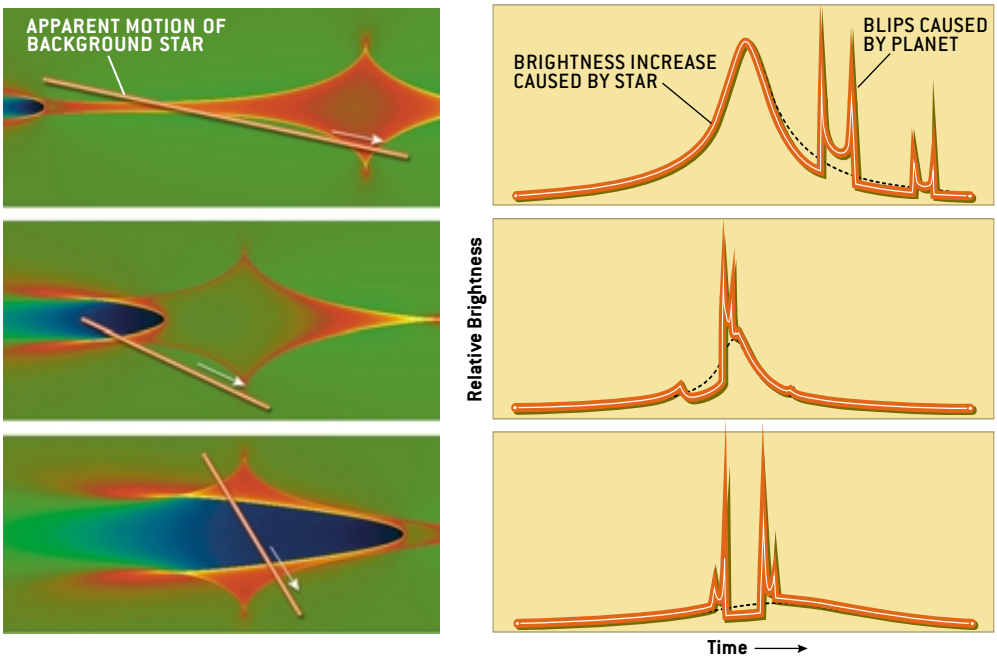
In the early 1990s several scientific teams, going by a slew of contrived acronyms—notably the French EROS, the American-Australian MACHO and the Polish-American OGLE—started to apply this method. Monitoring stars in the Large Magellanic Cloud, a small satellite galaxy of the Milky Way, the teams saw a total of almost two dozen microlensing events over seven years. These events lasted from a few weeks to several months, implying that the objects had approximately half



IF TELESCOPES HAD high enough resolution, a microlensing event would look like this. In practice, observers see only that the star got brighter.

ANDREW FRUCHTER *Space Telescope Science Institute and NASA (Abell 2218)*; YANNICK MELLIER *Institute of Astrophysics of Paris (dark matter)*; SARA CHEN *(microlensing)*

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SIMULATED STAR-PLANET microlensing event shows how a little planet can have a big effect on brightness. The color maps (*left*) show how magnification varies with position; the three diagrams correspond to three different distances between planet and star. As a background star moves through one of these maps, it is magnified to a small (*blue*), moderate (*green*), high (*red*) or very high (*yellow*) degree. Consequently, the brightness appears to fluctuate (*right*).

the mass of the sun. The number of events, however, was too low to explain more than a small fraction of the dark matter. Analogous techniques for other galaxies suggest that their dark matter cannot be made entirely of MACHOs, either.

The same teams also monitored stars toward the center of our Milky Way and observed more than 500 microlensing events in that direction, many more than expected. In this case, the lenses were not MACHOs but most likely normal stars with low mass. A small percentage appeared to be double stars, which caused the brightness to vary abruptly because of caustic crossings. Monitoring such caustic crossings can reveal the properties of stellar atmospheres and surfaces—the only way that astronomers have been able to discern such fine detail on distant stars. A few of the microlensing events may have been caused by stellar-mass black holes.

EXTRASOLAR PLANETS

Stellar microlensing can even detect planets. Several teams of observers—the PLANET (Probing Lensing Anomalies Network) group led by Penny D. Sackett of the University of Groningen in the Netherlands, the MPS (Microlensing Planet Search) group headed by David P. Bennett of the University of Notre Dame, and the MOA (Microlensing Observations in Astrophysics) group led by Philip Yock of Auckland University in New Zealand—have taken a detailed look at some of the events seen by the dark matter searches. In two cases, the observers saw a blip—an extra burst of brightening that might have been caused by a planet orbiting the lens star. Typically the blip lasted a few hours and boosted the brightness by a few percent.

Although these planet detections have not been independently confirmed, the principle is sound. It is only a question of time until gravitational lensing reveals an entire list of convincing planet candidates. Most other techniques look for the planet's effect on its parent star, which depends strongly on planet mass or size. But with the lensing technique, even a low-mass planet produces a caustic that leads to high magnification of the background star (*above*).

Five months ago a team of scientists headed by Kailash C. Sahu of the Space Telescope Science Institute detected the flickering of a handful of stars in the central part of the Milky Way. They tentatively interpreted it as microlensing by free-floating planets in the globular cluster M22—an exciting claim that, if confirmed, would have profound implications for the frequency of planetary-mass objects in the galaxy. Prior to this announcement, most astronomers had assumed that planets would be found only orbiting a star, not off on their own in deep space. It is yet another example of how scientists sometimes come closest to the truth when they are studying "illusions." SA

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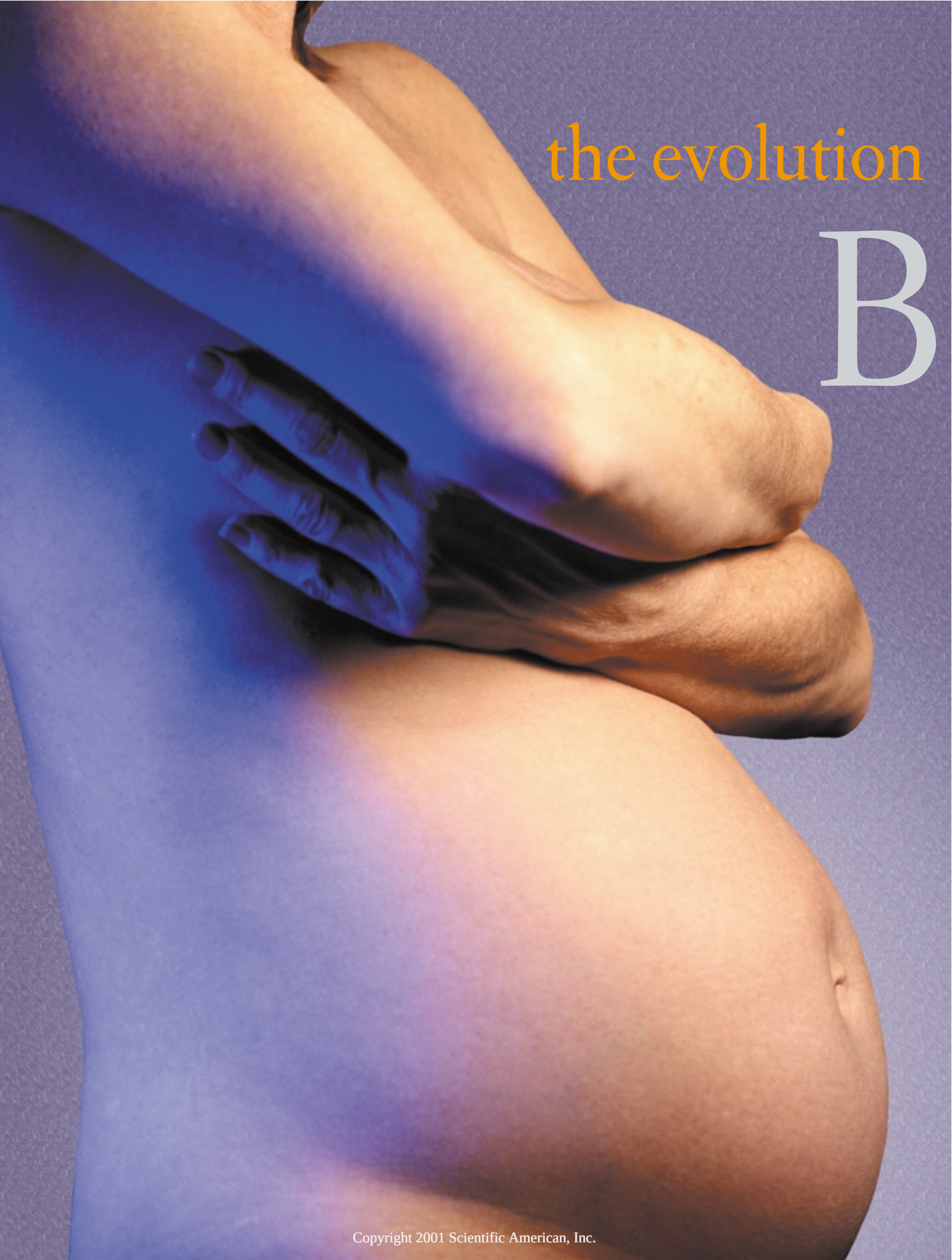
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JOACHIM WAMBSGANSS (*color map*); SARA CHEN (*graph*)

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of Human Birth

By Karen R. Rosenberg and Wenda R. Trevathan

The difficulties of childbirth have probably challenged humans and their ancestors for millions of years—which means that the modern custom of seeking assistance during delivery may have similarly ancient roots

GIVING BIRTH IN THE TREETOPS is not the normal human way of doing things, but that is exactly what Sophia Pedro was forced to do during the height of the floods that ravaged southern Mozambique in March 2000. Pedro had survived for four days perched high above the raging floodwaters that killed more than 700 people in the region. The day after her delivery, television broadcasts and newspapers all over the world featured images of Pedro and her newborn child being plucked from the tree during a dramatic helicopter rescue.

Treetop delivery rooms are unusual for humans but not for other primate species. For millions of years, primates have secluded themselves in treetops or bushes to give birth. Human beings are the only primate species that regularly seeks assistance during labor and delivery. So when and why did our female ancestors abandon their unassisted and

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solitary habit? The answers lie in the difficult and risky nature of human birth.

Many women know from experience that pushing a baby through the birth canal is no easy task. It's the price we pay for our large brains and intelligence: humans have exceptionally big heads relative to the size of their bodies. Those who have delved deeper into the subject know that the opening in the human pelvis through which the baby must pass is limited in size by our upright posture. But only recently have anthropologists begun to realize that the complex twists and turns that human babies make as they travel through the birth canal have troubled humans and their ancestors for at least 100,000 years. Fossil clues also indicate that anatomy, not just our social nature, has led human mothers—in contrast to our closest primate relatives and almost all other mammals—to ask for help during childbirth. Indeed, this practice of seeking assistance may have been in place when the earliest members of our genus, *Homo,* emerged and may possibly date back to five million years ago, when our ancestors first began to walk upright on a regular basis.

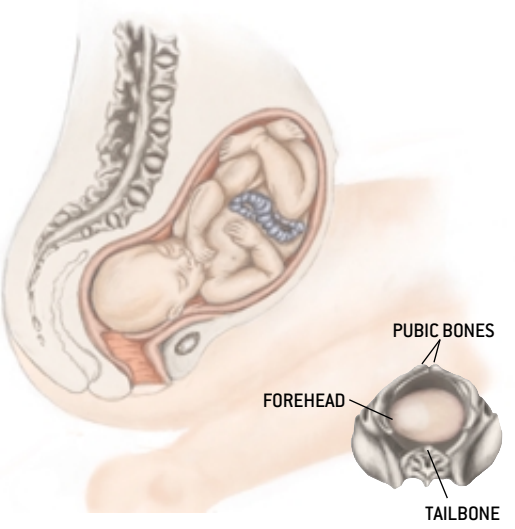
Tight Squeeze

TO TEST OUR THEORY that the practice of assisted birth may have been around for millennia, we considered first what scientists know about the way a primate baby fits through the mother's birth canal. Viewed from above, the infant's head is basically an oval, longest from the forehead to the back of the head and narrowest from ear to ear. Conveniently, the birth canal—the bony opening in the pelvis through which the baby must travel to get from the uterus to the outside world—is also an oval shape. The challenge of birth for many primates is that the size of the infant's head is close to the size of that opening.

For humans, this tight squeeze is complicated by the birth canal's not being a constant shape in cross section. The entrance of the birth canal, where the baby begins its journey, is widest from side to side relative to the mother's body. Midway through, however, this orientation shifts 90 degrees, and the long axis of the oval extends from the front of the mother's body to her back. This means that the human infant must negotiate a series of turns as it works its way through the birth canal so that the two parts of its body with the largest dimensions—the head and the shoulders—are always aligned with the largest dimension of the birth canal [*see illustration at right*].

To understand the birth process from the mother's point of view, imagine you are about to give birth. The baby is most likely upside down, facing your side, when its head enters the birth canal. Midway through the canal, however, it must turn to face your back, and the back of its head is pressed against your pubic bones. At that time, its shoulders are oriented side to side. When the baby exits your body it is still facing backward, but it will turn its head slightly to the side. This rotation helps to turn the baby's shoulders so that they can also fit between your pubic bones and tailbone. To appreciate the close correspondence of the maternal and fetal dimensions, consider that the average pelvic opening in human females is 13 centimeters at its largest diameter and 10 centimeters at its smallest. The average infant head is 10 centimeters from front to back, and the shoulders are 12 centimeters across. This journey through a passageway of changing cross-sectional shape makes human birth difficult and risky for the vast majority of mothers and babies.

If we retreat far enough back along the family tree of human ancestors, we would eventually reach a point where



BABY BORN FACING BACKWARD, with the back of its head against the mother's pubic bones, makes it difficult for a human female to guide the infant from the birth canal—the opening in the mother's pelvis (*insets*)—without assistance.

birth was not so difficult. Although humans are more closely related to apes genetically, monkeys may present a better model for birth in prehuman primates. One line of reasoning to support this assertion is as follows: Of the primate fossils discovered from the time before the first known hominid, *Australopithecus,* one possible remote ancestor is *Proconsul,* a primate fossil dated to about 25 million years ago. This tailless creature probably looked like an ape, but its skeleton suggests that it moved more like a monkey. Its pelvis, too, was more monkeylike. The heads of modern monkey infants are typically about 98 percent the diameter of the mother's birth canal—a situation more comparable with that of humans than that of chimps, whose birth canals are relatively spacious.

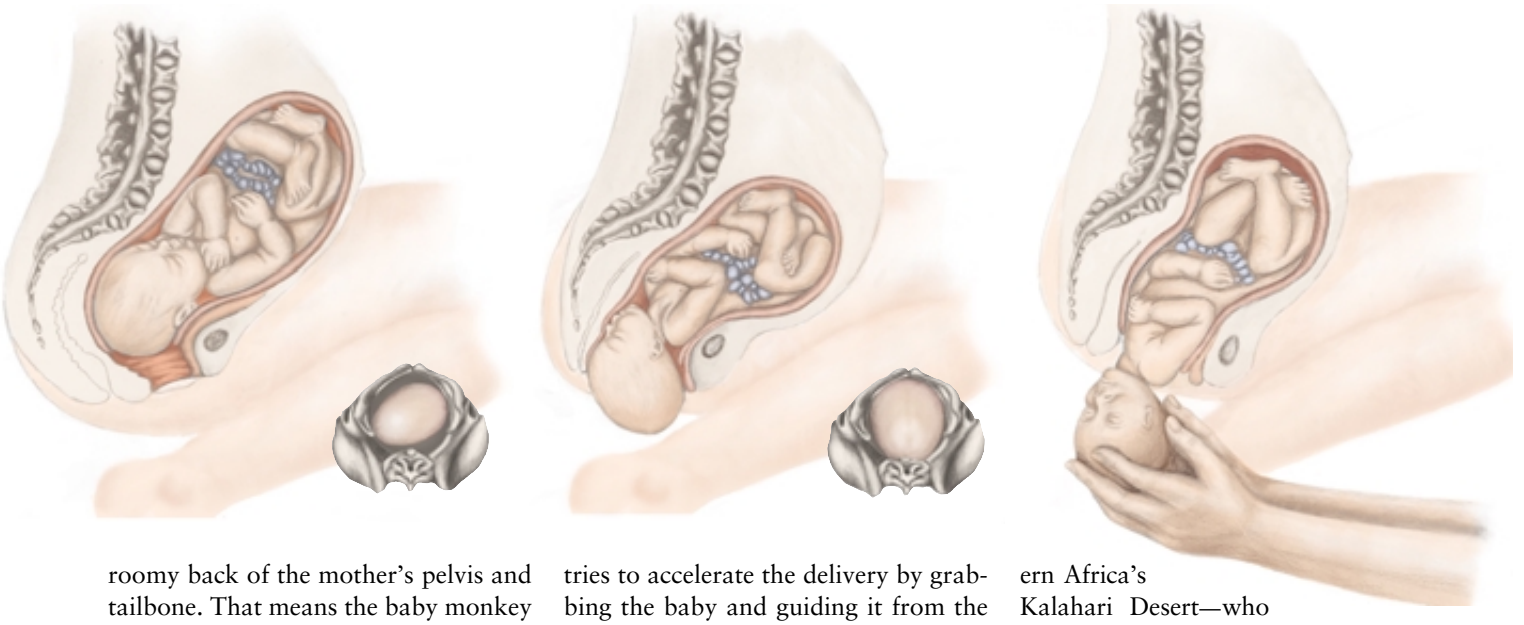
Despite the monkey infant's tight squeeze, its entrance into the world is less challenging than that of a human baby. In contrast to the twisted birth canal of modern humans, monkeys' birth canals maintain the same cross-sectional shape from entrance to exit. The longest diameter of this oval shape is oriented front to back, and the broadest part of the oval is against the mother's back. A monkey infant enters the birth canal headfirst, with the broad back of its skull against the

NINA FINKEL

THE AUTHORS

KAREN R. ROSENBERG and *WENDA R. TREVATHAN* bring different perspectives to the study of human birth. Rosenberg, a paleoanthropologist at the University of Delaware, specializes in pelvic morphology and has studied hominid fossils from Europe, Israel, China and South Africa. About 15 years ago she began studying the pelvis as a way to reconstruct the evolution of the birth process. That's when she met Trevathan, a biological anthropologist at New Mexico State University, whose particular interests include childbirth, maternal behavior, sexuality, menopause and evolutionary medicine. Both authors have experienced birth firsthand: Rosenberg has two daughters, and Trevathan is trained as a midwife.

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roomy back of the mother's pelvis and tailbone. That means the baby monkey emerges from the birth canal face forward—in other words, facing the same direction as the mother.

Firsthand observations of monkey deliveries have revealed a great advantage in babies' being born facing forward. Monkeys give birth squatting on their hind legs or crouching on all fours. As the infant is born, the mother reaches down to guide it out of the birth canal and toward her nipples. In many cases, she also wipes mucus from the baby's mouth and nose to aid its breathing. Infants are strong enough at birth to take part in their own deliveries. Once their hands are free, they can grab their mother's body and pull themselves out.

If human babies were also born face forward, their mothers would have a much easier time. Instead the evolutionary modifications of the human pelvis that enabled hominids to walk upright necessitate that most infants exit the birth canal with the back of their heads against the pubic bones, facing in the opposite direction as the mother (in a position obstetricians call "occiput anterior"). For this reason, it is difficult for the laboring human mother—whether squatting, sitting, or lying on her back—to reach down and guide the baby as it emerges. This configuration also greatly inhibits the mother's ability to clear a breathing passage for the infant, to remove the umbilical cord from around its neck or even to lift the baby up to her breast. If she tries to accelerate the delivery by grabbing the baby and guiding it from the birth canal, she risks bending its back awkwardly against the natural curve of its spine. Pulling on a newborn at this angle risks injury to its spinal cord, nerves and muscles.

For contemporary humans, the response to these challenges is to seek assistance during labor and delivery. Whether a technology-oriented professional, a lay midwife or a family member who is familiar with the birth process, the assistant can help the human mother do all the things the monkey mother does by herself. The assistant can also compensate for the limited motor abilities of the relatively helpless human infant. The advantages of even simple forms of assistance have reduced maternal and infant mortality throughout history.

Assisted Birth

OF COURSE, OUR ANCESTORS and even women today can and do give birth alone successfully. Many fictional accounts portray stalwart peasant women giving birth alone in the fields, perhaps most famously in the novel *The Good Earth,* by Pearl S. Buck. Such images give the impression that delivering babies is easy. But anthropologists who have studied childbirth in cultures around the world report that these perceptions are highly romanticized and that human birth is seldom easy and rarely unattended. Today virtually all women in all societies seek assistance at delivery. Even among the !Kung of southern Africa's Kalahari Desert—who are well known for viewing solitary birth as a cultural ideal—women do not usually manage to give birth alone until they have delivered several babies at which mothers, sisters or other women are present. So, though rare exceptions do exist, assisted birth comes close to being a universal custom in human cultures [*see box on next page*].

Knowing this—and believing that this practice is driven by the difficulty and risk that accompany human birth—we began to think that midwifery is not unique to contemporary humans but instead has its roots deep in our ancestry. Our analysis of the birth process throughout human evolution has led us to suggest that the practice of midwifery might have appeared as early as five million years ago, when the advent of bipedalism first constricted the size and shape of the pelvis and birth canal.

A behavior pattern as complex as midwifery obviously does not fossilize, but pelvic bones do. The tight fit between the infant's head and the mother's birth canal in humans means that the mechanism of birth can be reconstructed if we know the relative sizes of each. Pelvic anatomy is now fairly well known from most time periods in the human fossil record, and we can estimate infant brain and skull size based on our extensive knowledge of adult skull sizes. (The delicate skulls of infants are not commonly found preserved until the point when hu-

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BABY BORN FACING FORWARD makes it possible for a monkey mother to reach down and guide the infant out of the birth canal. She can also wipe mucus from the baby's face to assist its breathing.

mans began to bury their dead about 100,000 years ago.) Knowing the size and shape of the skulls and pelvises has also helped us and other researchers to understand whether infants were born facing forward or backward relative to their mothers—in turn revealing how challenging the birth might have been.

Walking on Two Legs

IN MODERN HUMANS, both bipedalism and enlarged brains constrain birth in important ways, but the first fundamental shift away from a nonhuman primate way of birth came about because of bipedalism alone. This unique way of walking appeared in early human ancestors of the genus *Australopithecus* about four million years ago [see "Evolution of Human Walking," by C. Owen Lovejoy; Scientific American, November 1988]. Despite their upright posture, australopithecines typically stood no more than four feet tall, and their brains were not much bigger than those of living chimpanzees. Recent evidence has called into question which of the several australopithecine species were part of the lineage that led to *Homo*. Understanding the way any of them gave birth is still important, however, because walking on two legs would have constricted the maximum size of the pelvis and birth canal in similar ways among related species.

The anatomy of the female pelvis from this time period is well known from two complete fossils. Anthropologists unearthed the first (known as Sts 14 and presumed to be 2.5 million years old) in Sterkfontein, a site in the Transvaal region of South Africa. The second is best known as Lucy, a fossil discovered in the Hadar region of Ethiopia and dated at just over three million years old. Based on these specimens and on estimates of newborns' head size, C. Owen Lovejoy of Kent State University and Robert G. Tague of Louisiana State University concluded in the mid-1980s that birth in early hominids was unlike that known for any living species of primate.

The shape of the australopithecine birth canal is a flattened oval with the greatest dimension from side to side at both the entrance and exit. This shape appears to require a birth pattern different from that of monkeys, apes or modern humans. The head would not have rotated within the birth canal, but we think that in order for the shoulders to fit through, the baby might have had to turn its head once it emerged. In other words, if the baby's head entered the birth canal facing the side of the mother's body, its shoulders would

Childbirth across Cultures



SQUATTING is one of the most typical positions for women to give birth in non-Western cultures.

NINA FINKEL; DANNY LEHMAN *Corbis (photograph)*

THE COMPLICATED CONFIGURATION of the human birth canal is such that laboring women and their babies benefit—by lower rates of mortality, injury and anxiety—from the assistance of others. This evolutionary reality helps to explain why attended birth is a near universal feature of human cultures. Individual women throughout history have given birth alone in certain circumstances, of course. But much more common is the attendance of familiar friends and relatives, most of whom are women. (Men may be variously forbidden, tolerated, welcomed or even required at birth.) In Western societies, where women usually give birth in the presence of strangers, recent research on birth practices has also shown that a doula—a person who provides social and emotional support to a woman in labor—reduces the rate of complications.

In many societies, a woman may not be recognized as an adult until she has had a baby. The preferred location of the delivery is often specified, as are the positions that the laboring women assume. The typical expectation in Western culture is that women should give birth lying flat on their backs on a bed, but in the rest of the world the most prevalent position for the delivery is upright—sitting, squatting or, in some cases, standing.

—K.R.R. and W.R.T.

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have been oriented in a line from the mother's belly to her back. This starting position would have meant that the shoulders probably also had to turn sideways to squeeze through the birth canal.

This simple rotation could have introduced a kind of difficulty in australopithecine deliveries that no other known primate species had ever experienced. Depending on which way the baby's shoulders turned, its head could have exited the birth canal facing either forward or backward relative to the mother. Because the australopithecine birth canal is a symmetrical opening of unchanging shape, the baby could have just as easily turned its shoulders toward the front or back of its body, giving it about a 50–50 chance of emerging in the easier, face-forward position. If the infant were born facing backward, the australopithecine mother—like modern human mothers—may well have benefited from some kind of assistance.

Growing Bigger Brains

IF BIPEDALISM ALONE did not introduce into the process of childbirth enough difficulty for mothers to benefit from assistance, then the expanding size of the hominid brain certainly did. The most significant expansion in adult and infant brain size evolved subsequent to the australopithecines, particularly in the genus *Homo*. Fossil remains of the pelvis of early *Homo* are quite rare, and the best-preserved specimen, the 1.5-million-year-old Nariokotome fossil from Kenya, is an adolescent often referred to as Turkana Boy. Researchers have estimated that the boy's adult relatives probably had brains about twice as large as those of australopithecines but still only two thirds the size of modern human brains.

By reconstructing the shape of the boy's pelvis from fragments, Christopher B. Ruff of Johns Hopkins University and Alan Walker of Pennsylvania State University have estimated what he would have looked like had he reached adulthood. Using predictable differences between male and female pelvises in more recent hominid species, they could also infer what a female of that species would have looked like and could estimate the shape of the birth canal. That shape turns out to be a flattened oval similar to that of the australopithecines. Based on these reconstructions, the researchers determined that Turkana Boy's kin probably had a birth mechanism like that seen in australopithecines.

In recent years, scientists have been testing an important hypothesis that follows from Ruff and Walker's assertion: the pelvic anatomy of early *Homo* may have limited the growth of the human brain until the evolutionary point at which the birth canal expanded enough to allow a larger infant head to pass. This assertion implies that bigger brains and roomier pelvises were linked from an evolutionary perspective. Individuals who displayed both characteristics were more successful at giving birth to offspring who survived to pass on the traits. These changes in pelvic anatomy, accompanied by assisted birth, may have allowed the dramatic increase in human brain size that took place from two million to 100,000 years ago.

Fossils that span the past 300,000 years of human evolution support the connection between the expansion of brain size and changes in pelvic anatomy. In the past 20 years, scientists have uncovered three pelvic fossils of archaic *Homo sapiens:* a male from Sima de los Huesos in Sierra Atapuerca, Spain (more than 200,000 years old); a female from Jinniushan, China (280,000 years old); and the male Kebara Neandertal—which is also an archaic *H. sapiens*—from Israel (about 60,000 years old). These specimens all have the twisted pelvic openings characteristic of modern humans, which suggests that their large-brained babies would most likely have had to rotate the head and shoulders within the birth canal and would thus have emerged facing away from the mother—a major challenge that human mothers face in delivering their babies safely.

The triple challenge of big-brained infants, a pelvis designed for walking upright, and a rotational delivery in which the baby emerges facing backward is not merely a contemporary circumstance. For this reason, we suggest that natural selection long ago favored the behavior of seeking assistance during birth because such help compensated for these difficulties. Mothers probably did not seek assistance solely because they predicted the risk that childbirth poses, however. Pain, fear and anxiety more likely drove their desire for companionship and security.

Psychiatrists have argued that natural selection might have favored such emotions—also common during illness and injury—because they led individuals who experienced them to seek the protection of companions, which would have given them a better chance of surviving [see "Evolution and the Origins of Disease," by Randolph M. Nesse and George C. Williams; SCIENTIFIC AMERICAN, November 1998]. The offspring of the survivors would then also have an enhanced tendency to experience such emotions during times of pain or disease. Taking into consideration the evolutionary advantage that fear and anxiety impart, it is no surprise that women commonly experience these emotions during labor and delivery.

Modern women giving birth have a dual evolutionary legacy: the need for physical as well as emotional support. When Sophia Pedro gave birth in a tree surrounded by raging floodwaters, she may have had both kinds of assistance. In an interview several months after her helicopter rescue, she told reporters that her mother-in-law, who was also in the tree, helped her during delivery. Desire for this kind of support, it appears, may well be as ancient as humanity itself. SA

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LARGE CLASSES, with their attendant distractions, are widely believed to hinder learning in many children.

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Legislators are spending billions to reduce class sizes.

Will the results be worth the expense?

Does Class Size Matter?

By Ronald G. Ehrenberg, Dominic J. Brewer, Adam Gamoran and J. Douglas Willms

BRUCE STRACHAN

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Education is the surest route to a life that is better in essentially all the ways that matter: intellectual, social, financial, even physical. It is a pillar of modern society and the subject of endless, often passionate arguments about how it can best be improved.

In the U.S., these debates have gone from simmer to boil following revelations that the country's secondary school students perform poorly relative to many Asian and European students. The news coincided with increasing concern over the nation's urban and lower-income suburban schools, too many of which are languishing at achievement levels far below those of middle-class and upper-middle-class suburban schools.

Of all the ideas for improving education, few are as simple or attractive as reducing the number of pupils per teacher. Unlike competing proposals for reform—such as ones based on the testing of teachers, on so-called charter schools and on vouchers—class-size reductions rarely elicit huge outcries or portend structural change. Testing of educators generally arouses the ire of teacher unions. And charter schools and vouchers involve financial credits that go to an alternative school; administrators and some legislators oppose these strategies because the credits usually come out of the budgets of local schools that are typically struggling.

With its uncomplicated appeal and lack of a big, powerful group of opponents, class-size reduction has lately gone from being a subject of primarily academic interest to a policy juggernaut. In the U.S., more than 20 states and the federal government have adopted policies aimed at decreasing class sizes, and billions of dollars have been spent or committed in the past few years. The rallying cry of smaller classes is also resounding in Canada, Australia, the U.K. and even Japan, whose record of secondary school performance is the envy of most other developed countries [*see box on page 84*].

Class-size reduction does have one obvious drawback: it costs plenty. It requires more teachers and possibly more classrooms, globes, blackboards and all the rest. These expenses can dwarf the price of alternative schemes, such as testing teachers or increasing their pay as a means of attracting better candidates. The state of California, for example, has been spending more than $1.5 billion annually over the past several years to reduce class sizes to 20 or fewer in kindergarten through grade three.

On the other hand, if smaller classes really do work, the economic windfall could be huge. It would accrue not just from the benefits of a better-educated workforce but also from other sources, such as the avoided medical costs and sick days of a healthier, more informed populace.

The surge of interest in smaller classes has spurred fresh analyses of the largest, most conclusive study to date, which took place in Tennessee in the late 1980s. At the same time, new data are flowing from various other initiatives, including the California program and a smaller one in Wisconsin. These results and analyses are finally offering some tentative responses to the questions that researchers must answer before legislators can come up with policies that make educational and economic sense: Do small classes in fact improve school achievement? If they do, in what grades do they accomplish the greatest good? What kind of students gain the biggest benefit? And most important of all: How great is the benefit?

Fewer students in a classroom seems to translate into less noise and disruptive behavior.

Overview/*Class Size*

- In the U.S., Australia, Canada and other countries, legislators have spent billions of dollars to reduce class sizes in primary schools or are proposing to do so. In California alone, officials have already invested about $5 billion.
- Hundreds of studies have examined whether smaller classes really do improve academic performance. But almost all of them have been inconclusive.
- An exception, the Student-Teacher Achievement Ratio (Project STAR), found that smaller classes particularly benefit minority students in early grades, such as first and second.

What Is It about Small Classes?

EDUCATORS HAVE a multitude of explanations for why smaller classes might be expected to improve academic performance, although frequently the ideas are based on anecdotes. Fewer students in a classroom seems to translate into less noise and disruptive behavior, which not

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INDIVIDUAL ATTENTION should increase as class size shrinks. Researchers suspect that the benefits of small classes derive from this attention as well as from fewer disruptions and more opportunities for teachers to use instructional methods (such as encouraging group discussions and assigning more written work) that usually do not succeed in large groups.

BRUCE STRACHAN

only gives the teacher more time for class work but also more freedom to engage students creatively—by dividing them into groups for specific projects, say. And smaller classes make it more likely that the teacher can bestow individual attention on struggling students.

Smaller classes also allow teachers to encourage more discussion, assign more writing and closely examine their students' written work. In other words, much of the benefit of reduced class size may depend on whether the teachers adapt their methods to take advantage of smaller classes [*see box on next page*]. Finally, some analysts believe that early grade school students in smaller classes are more likely to develop good study habits, higher self-esteem and possibly other beneficial cognitive traits—which may very well persist for years, even after the students have gone back to regular-size classes. All these ideas are largely speculative, however, because hardly any research has attempted to nail down the ways that smaller class sizes may benefit children.

One way investigators have attempted to analyze the effects of class size is by reviewing existing data, such as records kept by the U.S. Department of Education. These show that between 1969 and 1997, the average number of pupils per teacher in American public and private elementary schools fell from 25.1 to 18.3, a decline of greater than 27 percent. In secondary schools, the number also fell, from 19.7 to 14.0.

How much did academic performance change while these steep drops in pupil-teacher ratios were occurring? Not

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A statistician has called STAR "one of the greatest experiments in education in United States history."

a lot. Data from the National Assessment of Educational Progress—a series of tests that is the only U.S.-wide indicator of student knowledge in reading, mathematics, science and other subjects—show no significant or consistent gains. In some specific age and subject categories, such as 17-year-olds and science, performance actually decreased slightly.

What the Record Shows

BUT DO THESE findings mean that class size makes no difference? Not necessarily. For a variety of reasons, most researchers, including us, pay little attention to those figures. For instance, schools strive for more than just high test scores; they also usually try to keep their dropout rates low. And indeed, the dropout rate for students aged 16 to 24 fell from 15 to 11 percent over that period. Because dropouts generally come from the low end of the achievement distribution, a reduction in the dropout rate could be expected to pull down average test scores in the upper grades.

Another reason for discounting those data goes right to the heart of the difficulties in this field of study: it is hard to isolate the effects of class size from the myriad factors that influence student performance. Ideally, U.S. students would all come from families that are financially well off, with two highly educated, English-speaking parents who are involved in their children's schooling. Teachers would all be creative and have complete mastery of their subject matter. Schools would be nicely outfitted with libraries, computers and other resources.

The reality is that in 1995 only 68 percent of American students came from families with two parents in the home—down from 85 percent in 1970. The fraction of children who had difficulty speaking English rose from 2.8 percent in 1979 to 5.1 percent in 1995. And the percentage of children living in poverty increased from 14.9 in 1970 to 20.2 in 1995. There was some good news: the median level of education among parents increased a bit during that time period, as did the level among teachers, whose average amount of experience also went up.

The bottom line is that demographic shifts make it very difficult to tease out the effect of reductions in pupil-teacher ratios. Well-designed experiments strive to cancel out the influence of those other factors by randomly assigning students and teachers to different class sizes and by including a large sample. Over the past 35 years, hundreds of studies and analyses of existing data (such as the Department of Education records) have focused on class size. Most found some evidence that smaller classes benefit students, particularly in the early grades, and especially kids at risk of being underachievers. Unfortunately, most of these studies were poorly designed. Teacher and student assignments were rarely sufficiently random; a number of studies were simply too brief or too small, and too few had independent evaluation.

The notable exception was the Tennessee study mentioned earlier. Frederick Mosteller, a distinguished Harvard Uni-

INGREDIENT X: A TEACHER'S ADAPTABILITY

The conventional wisdom about small classes is that they minimize disruptions. They also free teachers to bestow individual attention and to use creative approaches, such as letting students work in small groups. Where discipline is not a significant problem, then, any achievement gains resulting from reducing class size would be expected to derive mainly from the teacher's use of methods that take advantage of smaller classes.

But study after study has found that educators rarely change their instructional styles to match the size of their class. In fact, data from Tennessee's Project STAR, the best study of small classes to date, show how hard it is to change the way teachers practice their craft: even a summer professional development program did not prompt participants to modify the way they worked with smaller classes. Moreover, educators seem to devote the same overall amount of time to individual instruction in small and large classes. With fewer kids in a class, each child gets a bigger share of that time, but the increase is not nearly enough to account for any significant differences in academic performance.

If teachers work in more or less the same way regardless of class size, what accounts for the benefits of smaller classes seen in experimental studies such as STAR? One likely explanation is that teachers who have naturally settled on methods well suited to smaller classes—those who already like splitting the class up into small groups, who develop personal relationships with students and who emphasize hands-on projects—do very well when they are actually given small classes. Their improved performance pulls up the average, which probably also gets a lift from fewer disciplinary problems.

This interpretation is consistent with findings that substantial performance gains from small classes occur in the early elementary grades and do not accumulate beyond first or second grade. Kindergarten and first-grade teachers in particular tend to use small groups, hands-on projects and personal relationships with students.

To confirm this scenario, researchers would have to study the relationships among class size, instructional activities and achievement at various grade levels. That no one has done this work is surprising, considering how useful it would be to administrators in deciding where and how to use small classes.

—R.G.E., D.J.B., A.G. and J.D.W.

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MILESTONE STUDIES ON CLASS SIZE

Project	State	Dates	Type of program	Students participating	Approximate cost	Small class size	Key findings
STAR	Tennessee	1985 to 1989	Demonstration experiment	Approximately 10,000	$12 million	13 to 17	Significant performance benefit of 0.2 standard deviation; larger gains for minority pupils
Class Size Reduction	California	1996 to present	Statewide initiative	1.8 million	$5 billion	Fewer than 20	Small performance gain of about 0.05 to 0.1 standard deviation; no greater gains for minorities
SAGE	Wisconsin	1996 to 2001	Pilot project	64,000	$103 million	12 to 15	Significant performance advantage of 0.2 standard deviation; larger gains for minority pupils

versity statistician, has called it "one of the greatest experiments in education in United States history." The Student-Teacher Achievement Ratio, better known as Project STAR, was a state-sponsored, $12-million demonstration program. Students entering kindergarten were randomly assigned to one of three kinds of classes: a small class of 13 to 17 students, a regular-size class of 22 to 26, or a regular-size class with both a teacher and a full-time teacher's aide.

The students remained in whatever category they had been assigned to through the third grade, after which they joined a regular classroom in the fourth. To ensure that teaching quality did not differ, teachers were randomly assigned to small and regular-size classrooms. Few teachers received any special training for working with small classes, and there were no new curricular materials.

Some 70 schools and 46 districts participated in the first year, assigning 1,900 students to 128 small classes, 2,300 students to 101 regular classes, and 2,200 students to 99 regular classes with an aide. By the end of the study, four years later, the total student roster had grown from 6,400 to 12,000.

Shining STAR

AFTER THE STUDY ended in 1989, researchers conducted dozens of analyses of the data. One of the few points analysts agree on is that the teacher's aides did not make any difference. Researchers disagree about how long students have to be in smaller classes to get a benefit, how big that benefit is, and when it becomes noticeable—in other words, the collected findings have yielded no consensus on the issues of real interest to policymakers.

Jeremy Finn of the State University of New York at Buffalo and Charles M. Achilles of Eastern Michigan University found "an array of benefits of small classes" in their review. Finn calculated that students in the small classes outperformed their counterparts in regular-size classes by a fifth of a standard deviation and that this sizable jump in achievement generally appeared by the first grade. Best of all, this advantage seemed to persist into upper elementary grades even after students returned to larger classes.

How big a difference is a fifth of a standard deviation? Suppose you had two kindergarten pupils, each as average as it is possible to be, statistically speaking. Both are in the 50th percentile, meaning that half of the other pupils perform better than these two and that half do worse. Put one student in a small class and leave the other in a regular class. After a year, the pupil in the small class will be in the 58th percentile—in other words, the student will be doing better than nearly 60 percent of his or her peers—while the other student will still be doing better than only 50 percent.

Finn and Achilles also found that the effect was stronger for minority students, by a factor of two to three. In other words, black and Hispanic children improved by two fifths to three fifths of a standard deviation—a significant finding from a policy standpoint, because minorities typically score about one standard deviation below nonminorities on standard tests.

A few analysts, notably Eric Hanushek of Stanford University's Hoover Institute, criticize STAR and some of the key conclusions reached by its proponents. Hanushek agrees that students can gain an initial benefit from small classes. But, he argues, the STAR data cannot be used to prove that the gains persist for years after a student has returned to regular-size classes. If a child is still doing well years later, it is hard to know how

THE AUTHORS

RONALD G. EHRENBERG, DOMINIC J. BREWER, ADAM GAMORAN and *J. DOUGLAS WILLMS* collaborated on a paper surveying studies of class size and academic performance for the May 2001 issue of *Psychological Science in the Public Interest* [*see More to Explore, on page 85*]. Ehrenberg is the Irving M. Ives Professor of Industrial and Labor Relations and Economics at Cornell University and the author of *Tuition Rising: Why College Costs So Much* (Harvard University Press, 2000). Brewer, who specializes in the economics of education, is the director of Rand Education, which analyzes programs and policies on education issues, and is a visiting professor of economics at the University of California, Los Angeles. Gamoran, a former Fulbright scholar, is a professor of sociology and educational policy studies at the University of Wisconsin–Madison. Willms is a professor and director of the Canadian Research Institute for Social Policy at the University of New Brunswick.

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THE ASIAN PARADOX: Huge Classes, High Scores

By Glenn Zorpette

Study after study ranks schoolchildren in Japan and other developed Asian countries among the best in the world, particularly on standardized tests of mathematics and science. U.S. high school students, meanwhile, have slipped somewhere below those in Greece and Lithuania—never mind Taiwan and Singapore—in advanced math and physics.

Yet classes in Asia are large. Forty students for one teacher would be business as usual in most of the region. In contrast, elementary school class sizes in the U.S. average about 24, according to the U.S. Department of Education.

How do Asian kids do so well in classes so big? Take Japan, where the discipline in classrooms is legendary. That discipline isn't imposed by fearsome teachers, according to Catherine Lewis, an expert on the Japanese educational system and a senior researcher at Mills College. Instead students are honored to be chosen to lead lessons, and they take turns calling the class to order, experiencing firsthand what it is like to quiet down an unruly group. Thus, teachers manage the class by relying on "the cumulative, general power of self-reflection, rather than punishing and rewarding," Lewis explains.

Japanese teachers and students also spend much more time together—the school year is about 40 days longer than in the U.S.—and more time bonding with one another, at school festivals and on field trips and hikes. "There's an incredibly strong emphasis on class, group and school being meaningful entities for the children," Lewis says.

Japan's prowess is also sustained by something it doesn't have: ethnic and linguistic diversity. Finally, Asian parents are far less likely than Americans to be divorced and are more likely to be involved in their children's education.

Of course, there's a downside to the Asian system: rigid national standards don't do much to foster creativity. And in Japan some children strive hard to excel partly because they become burdened early on by the fear of failing.



JON BURBANK *The Image Works*

Given the deep cultural differences, it's not clear which parts of the Asian formula could work in America. But the Asian experience does show what can be done when discipline grows from the bottom up. In that kind of environment, elementary school teachers can focus on "creating happy memories," as one Japanese teacher described her main purpose to Lewis.

Glenn Zorpette is a writer based in New York.

much of that performance stems from other factors, such as a supportive home.

Hanushek also disagrees with an analysis indicating that the benefits of small classes accumulate—that students who stay in such classes for several grades widen the performance gap with their peers in large classes year by year. When he studied the four-year gains of STAR students who were in the smaller classes from kindergarten through grade three, he did not find the gains to be larger than those logged in kindergarten.

He and others have also shown that during the study, too many children migrated from the regular to the small classes, probably because school personnel caved in to parent demands. And Hanushek asserts that STAR had insufficient checks to ensure good randomization of teacher and student assignments. These are good points, but they do not really undermine STAR's finding of a statistically significant benefit of being in a class having 13 to 17, rather than 23, students.

Two Views: California and Wisconsin

THE CHALLENGE for legislators now is to come up with sensible policies based on sound interpretations of STAR and other studies. Unfortunately, the largest public program so far, California's multibillion-dollar effort, begun in 1996, stands more as a model of what *not* to do than as an initiative worthy of emulation. That state is trying to reduce classes in kindergarten through grade three from a maximum of 33 to a maximum of 20 in rich and poor districts alike—despite a shortage of qualified teachers that is acutest in low-income areas. This across-the-board approach may be politically expedient, but it seems to have actually exacerbated the disparity in resources available to rich and poor schools in California.

Not surprisingly, the program triggered an increased demand for teachers in almost all California districts. The better-paying, more affluent districts got a lot of the best teachers—including a fair number that came from the poorer districts, which were already having trouble recruiting and retaining good teachers. These mostly urban districts wound up with many inexperienced teachers who had no credentials. The rapidly growing urban districts also had little space to build new classrooms, and some of them could not whittle class sizes down to 20, which they had to do before they could qualify for the state funds.

The California experience has not led to any firm conclusions about whether class size affects performance. There was no randomization, no state testing system in place initially and no evaluation procedures. Nevertheless, several researchers who looked at the first years have managed to make a few points concerning third-grade students, the only ones for whom statewide test-score data are available. The evaluators found a very small but statistically significant achievement advantage in reading, writing and mathematics for students in the

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classes that had been reduced to 20 or fewer pupils, as compared with the classes of more than 20. In contrast to the STAR findings, though, the tiny effect did not appear to vary for students of different races or ethnic or socioeconomic backgrounds.

Wisconsin's Student Achievement Guarantee in Education (SAGE), also begun in 1996, was a five-year pilot study. It was small—class sizes were reduced in just 14 schools—but noteworthy because it targeted schools at which at least 30 percent of the students were below the poverty level, compared with California's one-size-fits-all approach. It brought down the average number of pupils per teacher in kindergarten through third grade to 13.47 from 22.42.

Analysts have so far compared first-grade students in SAGE schools with first-grade students in a group of schools serving populations that have similar family income, achievement, enrollment and racial compositions. The results from the first two years are in line with those from STAR: first-grade SAGE students made gains that are statistically significant—and that are considerably larger than those calculated for the California initiative.



STORAGE ROOMS and such may have to be converted to classrooms to accommodate smaller—and therefore more numerous—classes. And many districts will have to build new facilities at steep costs. The authors urge administrators to also consider alternative methods of improving education—such as hiring teachers with excellent verbal skills and educational backgrounds.

Cheaper Alternatives?

STUDIES such as STAR and SAGE have made it hard to argue that reducing class sizes makes no difference. On the other hand, the California initiative has shown that the strategy, applied with too little forethought and insight, can consume billions of dollars and, at least in the short run, produce only minuscule gains and even some losses.

Alternatives need to be considered. What little work has been done on teacher competence suggests that students perform better with teachers who have greater verbal ability and, at the secondary school level, better knowledge of their subject matter. Astoundingly, however, when choosing among applicants for teaching positions, school districts often do not select the candidates with the strongest academic backgrounds and the highest scores on aptitude tests. Rather school officials tend to favor teachers who live nearby, graduated from local colleges and possess proved classroom-management skills.

Emphasizing aptitude and subject-matter competence in hiring decisions wouldn't cost anything, although getting more high-aptitude candidates to go into teaching would probably require higher salaries. So far no one has studied the relative costs of attracting better teachers as opposed to reducing class sizes.

Legislators and administrators need much more solid information on the relative costs of the other options before they can make sensible policy decisions. Let's hope they get it before they commit billions more to reducing classes across the board—and before millions of kids get covered by blanket policies that may be less effective than they could be. SA

MORE TO EXPLORE

Standards for Our Schools. Mark S. Tucker and Judy Codding. Jossey-Bass, 1998.

Research: Sizing Up Small Classes. Linda Jacobson in Education Week on the Web; February 28, 2001. Available at **www.edweek.org/ew/ewstory.cfm?slug=24classsize.h20**

Class Size and Student Achievement. Ronald G. Ehrenberg, Dominic J. Brewer, Adam Gamoran and J. Douglas Willms in *Psychological Science in the Public Interest,* Vol. 2, No. 2, pages 1–30; May 2001. Available at **www.psychologicalscience.org/newsresearch/publications/journals/pspi/ pspi2_1.pdf**

The National Educational Association page of links to Internet sources on class size is available at **www.nea.org/issues/classsize/resources.html**

Information from the California School Boards Association about class size is available at **www.csba.org/calschools/perform.html**

Information from the Class Research Consortium on class-size reduction is available at **www.classize.org**

BRUCE STRACHAN

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GROUND FAULT CIRCUIT INTERRUPTERS

Current Safety

That strange electrical outlet with the TEST and RESET buttons is rapidly becoming widespread. Now required by the U.S. National Electrical Code in new bathroom, kitchen, garage and outdoor receptacles, the ground fault circuit interrupter (GFCI) can protect you from nasty electric shocks and electrocution.

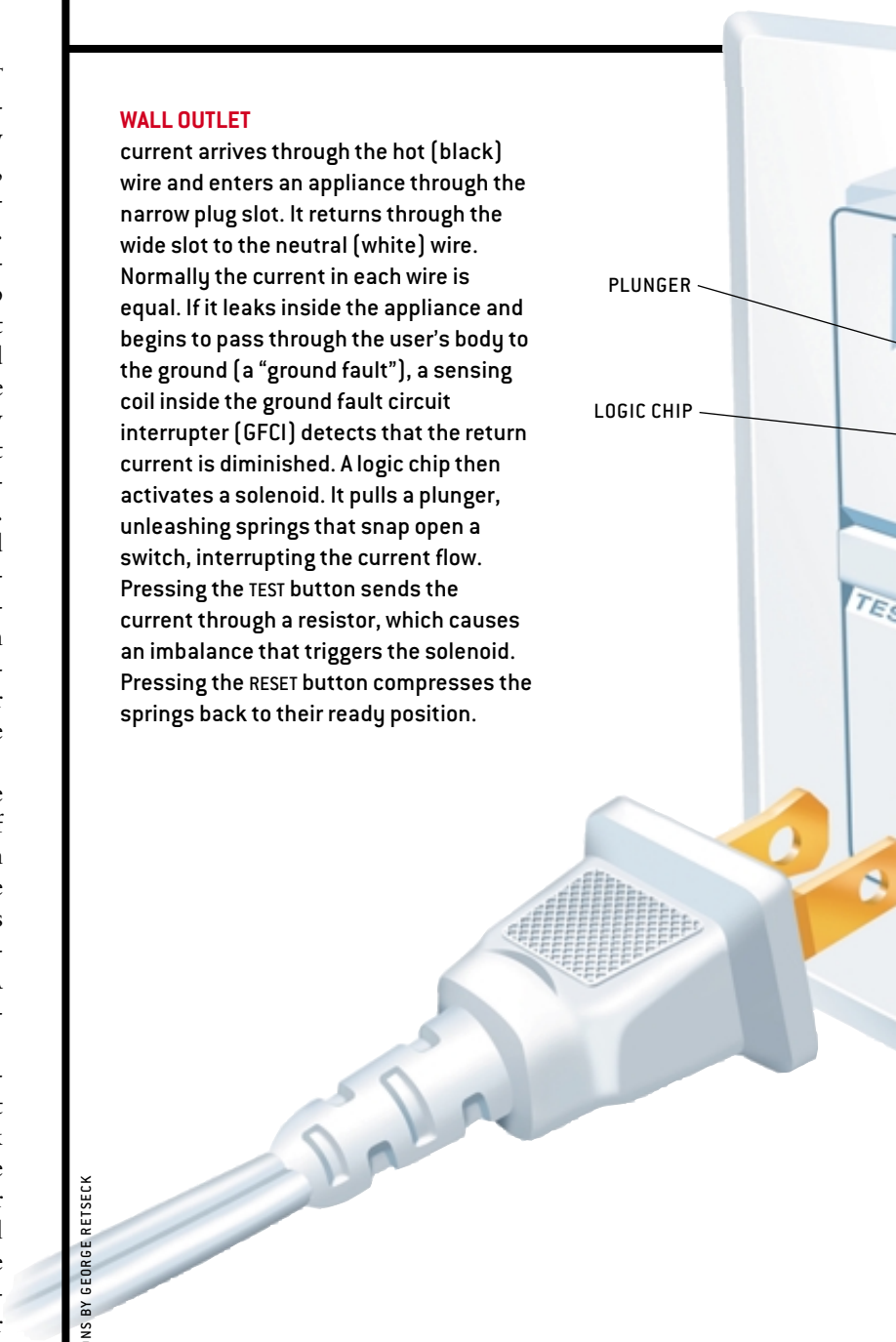
People often assume that a building's circuit breakers or fuses will protect them. But these switches trip primarily when wiring short-circuits or an outlet overloads, which could heat the building's wiring and start a fire. Typical home breakers don't trip until the current surpasses 15 or 20 amps, yet a current of only 0.1 amp through a person's body can cause a heart attack, according to Matt Marone, who teaches experimental and applied physics at Mercer University.

Most residential shocks are caused by a "ground fault" in a tool or appliance. A loose or worn internal wire, splashed water or even high humidity electrifies the outside of the appliance. The current can then pass through someone's body to the ground, especially if he or she is wet, standing in water, or touching metal sinks or plumbing. That's when the GFCI cuts the power.

Considering that the average GFCI costs a mere $10, its inner workings are an elegant exploitation of the fundamental laws of electricity and magnetism [*see diagrams at right*]. It springs into action when the current returning to the outlet from an appliance is less than the current feeding the appliance, which indicates a "leak" resulting from a ground fault. A GFCI can detect leaks as small as 0.005 amp and interrupt the current as fast as 1/40 of a second.

Nevertheless, GFCIs will not save do-it-yourselfers who decide to tinker with an outlet without shutting off its circuit breaker. "If you touch the black and the white wires with different hands and you are insulated from the floor by, say, rubber sneakers or boots, the current out of the outlet and back to it will be balanced; there will be no ground fault," Marone says. "But you could die because the 120-volt potential across your arms will create a current in your body that could stop your heart." Not even physics can overcome foolish behavior. —*Mark Fischetti*

WALL OUTLET
current arrives through the hot (black) wire and enters an appliance through the narrow plug slot. It returns through the wide slot to the neutral (white) wire. Normally the current in each wire is equal. If it leaks inside the appliance and begins to pass through the user's body to the ground (a "ground fault"), a sensing coil inside the ground fault circuit interrupter (GFCI) detects that the return current is diminished. A logic chip then activates a solenoid. It pulls a plunger, unleashing springs that snap open a switch, interrupting the current flow. Pressing the TEST button sends the current through a resistor, which causes an imbalance that triggers the solenoid. Pressing the RESET button compresses the springs back to their ready position.



ILLUSTRATIONS BY GEORGE RETSECK

Ideas for the text and illustrations were supplied by Matt Marone, assistant professor of physics at Mercer University in Macon, Ga.

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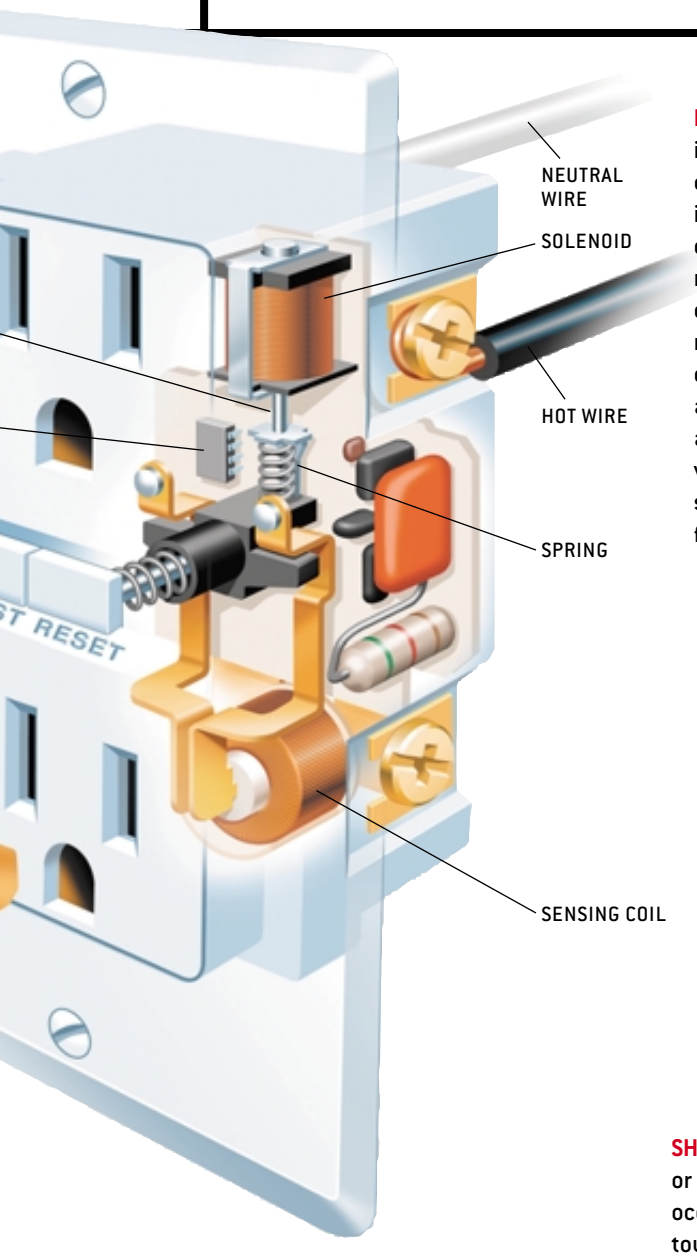
DID YOU KNOW . . .

➤ CAN'T LET GO: A shock can progress to electrocution when a person who has, say, touched a knife to a toaster coil can't let go of the implement. "A flow of only 0.01 amp will contract your muscles" and hold them there, says Matt Marone of Mercer University. If you witness this, turn off the outlet's wall switch or breaker, pull the plug or, as a last resort, knock the person away. But don't grab and hold on, because you will become electrified yourself.

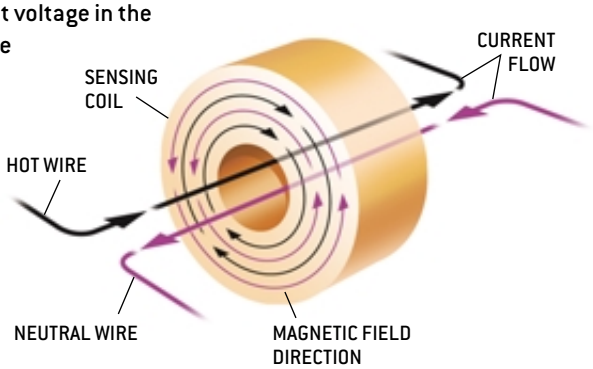
➤ DOWN THE LINE: One GFCI can protect several receptacles farther down the same line, if properly wired. You can check by pressing the TEST button, then plugging a lamp or radio into the GFCI outlet and others nearby to make sure the power is off.

➤ PORTABLE PROTECTION: If you're not handy or can't alter old outlets, you can buy a stand-alone GFCI that plugs into an existing three-prong outlet. GFCI extension cords are also available.

➤ ELECTROCUTIONS: Nearly 200 Americans were electrocuted in 1997 in nonindustrial settings (latest data), according to the National Center for Health Statistics; this is down 39 percent from a decade earlier. Tens of thousands were injured. The leading causes were bad building wiring and faulty consumer products. Other causes: hedge trimmers cutting their own power cord, electric hair curlers or dryers falling into a wet sink, and drilling into a wall and hitting an electrical cable.



HOT AND NEUTRAL WIRES inside a GFCI outlet lie closely parallel. The current in each creates a magnetic field, which induces a voltage in a surrounding sensing coil of wire. Because the two currents flow in opposite directions, the fields nearly cancel and the net voltage in the coil is virtually zero. If the returning (neutral) current drops, however, a stronger voltage arises in the coil. A voltage comparator signals a logic chip to fire the GFCI into action.

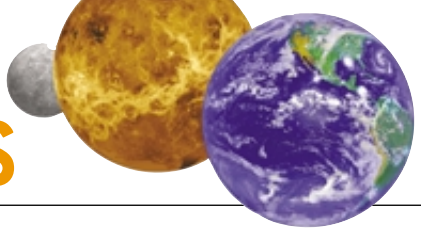


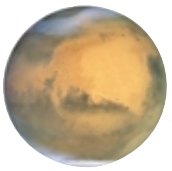


SHOCK or electrocution can occur when a person touches a live conductor or holds a tool or appliance that has been inadvertently electrified by worn internal wiring, water or even high humidity.

Have a topic for a future column? Send it to workingknowledge@sciam.com

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A Short Stroll through the Solar System

TOUR THE BRAIN STEM OF PLANETARY SCIENCE—AND SEE WHAT KIND OF ROBOT $1.5 BILLION BUYS

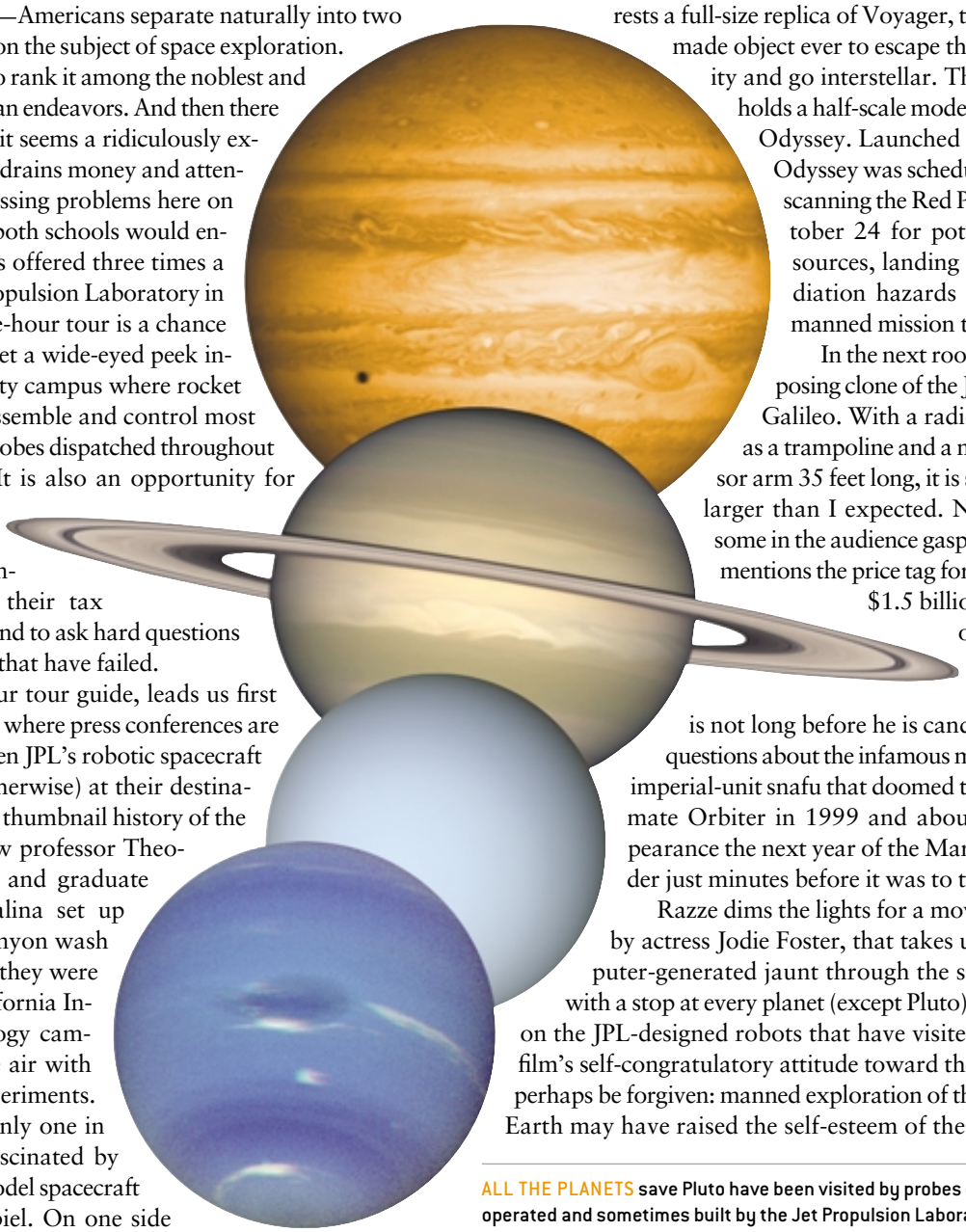
BY W. WAYT GIBBS

PASADENA, CALIF.—Americans separate naturally into two schools of thought on the subject of space exploration. There are those who rank it among the noblest and most heroic of human endeavors. And then there are those to whom it seems a ridiculously expensive hobby that drains money and attention from more pressing problems here on Earth. Students of both schools would enjoy the public tours offered three times a month at the Jet Propulsion Laboratory in Pasadena.The three-hour tour is a chance for space buffs to get a wide-eyed peek inside the high-security campus where rocket scientists design, assemble and control most of the deep-space probes dispatched throughout our solar system. It is also an opportunity for the fiscally suspicious to see firsthand what newfangled contraptions their tax dollars are buying and to ask hard questions about the missions that have failed.

Mark Razze, our tour guide, leads us first into the auditorium where press conferences are sometimes held when JPL's robotic spacecraft arrive (intact or otherwise) at their destinations. Razze gives a thumbnail history of the lab, explaining how professor Theodore von Kármán and graduate student Frank Malina set up shop in this dry canyon wash 65 years ago, after they were kicked off the California Institute of Technology campus for fouling the air with their rocketry experiments. But I am not the only one in the group more fascinated by the auditorium's model spacecraft than by Razze's spiel. On one side rests a full-size replica of Voyager, the first man-made object ever to escape the sun's gravity and go interstellar. The other side holds a half-scale model of the Mars Odyssey. Launched in April, the Odyssey was scheduled to begin scanning the Red Planet on October 24 for potential water sources, landing sites and radiation hazards for a future manned mission to Mars.

In the next room sits an imposing clone of the Jupiter probe Galileo. With a radio dish as big as a trampoline and a magnetic sensor arm 35 feet long, it is several times larger than I expected. Nevertheless, some in the audience gasp when Razze mentions the price tag for the mission: $1.5 billion (nearly all of that spent on 10 years of labor). It is not long before he is candidly fielding questions about the infamous metric-versus-imperial-unit snafu that doomed the Mars Climate Orbiter in 1999 and about the disappearance the next year of the Mars Polar Lander just minutes before it was to touch down.

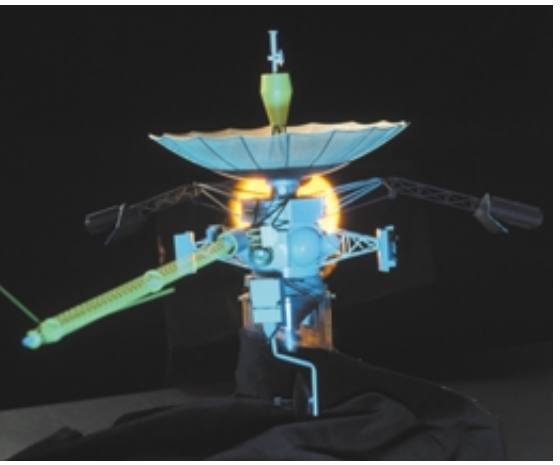
Razze dims the lights for a movie, narrated by actress Jodie Foster, that takes us on a computer-generated jaunt through the solar system, with a stop at every planet (except Pluto) to elaborate on the JPL-designed robots that have visited them. The film's self-congratulatory attitude toward the probes can perhaps be forgiven: manned exploration of the space near Earth may have raised the self-esteem of the species, but



ALL THE PLANETS save Pluto have been visited by probes designed, operated and sometimes built by the Jet Propulsion Laboratory.

NASA

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ROGER RESSMEYER *Corbis*

COMPUTER MODEL of Galileo spacecraft is not nearly as impressive as the full-size mock-up on display at JPL.

most of what planetary scientists understand about the universe they owe to the disposable machines that function as eyes and hands in a kind of nervous system spread across eight billion miles.

Our next stop is the brain stem of that nervous system: the spaceflight operations facility, a.k.a. mission control. From a raised gallery we look down onto a room stuffed with computers and monitors. A large screen on the wall shows two timers. One counts up: "Mars Odyssey Launch: +067:06:32:20." The other timer counts down: "Genesis Launch: –46:19:02:30." (Genesis actually launched on August 8, about 10 days late.)

Swiveling a model of a 70-meter-diameter radio dish, JPL staffer Pete Landry explains how a network of such transceivers in Canberra, Australia, Goldstone, Calif., and Madrid communicates with the several dozen spacecraft now drifting through deep space. Aimed with precision of a thousandth of a degree, the big dishes can transmit command signals up to 400 kilowatts in power. And they can receive images, scientific measurements and maintenance information from spacecraft so distant that by the time the signals reach Earth they have less than one ten-billionth the power of a digital wristwatch.

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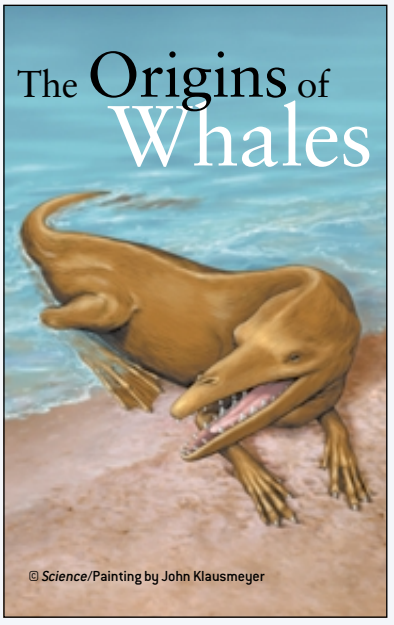
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ON THE WEB

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FEATURED STORY

Researchers have long debated how whales came to live in the seas. Fossils suggested that extinct hyena-like creatures known as mesonychians gave rise to the leviathans. More recently, however, DNA evidence has indicated that whales descended from artiodactyls—the group that includes hippos, pigs and ruminants.

Now fossils from Pakistan could settle the matter once and for all. Using the newly found bones, paleontologists are connecting the evolutionary dots between whales and artiodactyls. In fact, the skeletons appear to be consistent with the controversial claim that the hippo is the whale's closest living relative.

ASK THE EXPERTS

How do water softeners work?
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VOYAGES

Our tour ends with a visit to another observation deck inside the spacecraft assembly facility. On the other side of the glass, giant fans hum as every three minutes they filter the entire volume of air in the four-story bay to maintain cleanroom conditions. Chunks of raw technology tethered to oscilloscopes and power supplies sit on a table in the room. Landry explains that the gizmo under construction is a "scatterometer," which, once completed and mounted on a Japanese satellite scheduled to launch next spring, will be able to monitor maritime wind speed and direction from space by recording the "cat's paw" waves that form when the wind skims the ocean.

By the end of the tour we have covered only a small part of the 177-acre complex, but it has still been a lot of walking, and the older guests with canes head straight for the benches at the visitor center. Guides can take reservations for the free public tours (call 818-354-9314) or make special arrangements for groups of 10 or more visitors. (Note that group tours typically must be booked six to nine months beforehand.) More information about the public tours is available online at www.jpl.nasa.gov/pso/

Plan to spend half an hour before or after the tour perusing the visitor center, which exhibits photographs, models and multimedia presentations on the lab's planetary, astrophysical and remote sensing missions. And because freeway traffic can be congested and parking is tight at the lab, allow 90 minutes' travel time from downtown Los Angeles. SA





JPL TOUR is an opportunity to learn about the Deep Space Network (*top*), look over the shoulders of mission controllers (*bottom*) and see spacecraft under construction.

JPL/CALTECH/NASA (*top*); ROGER RESSMEYER *Corbis* (*bottom*)

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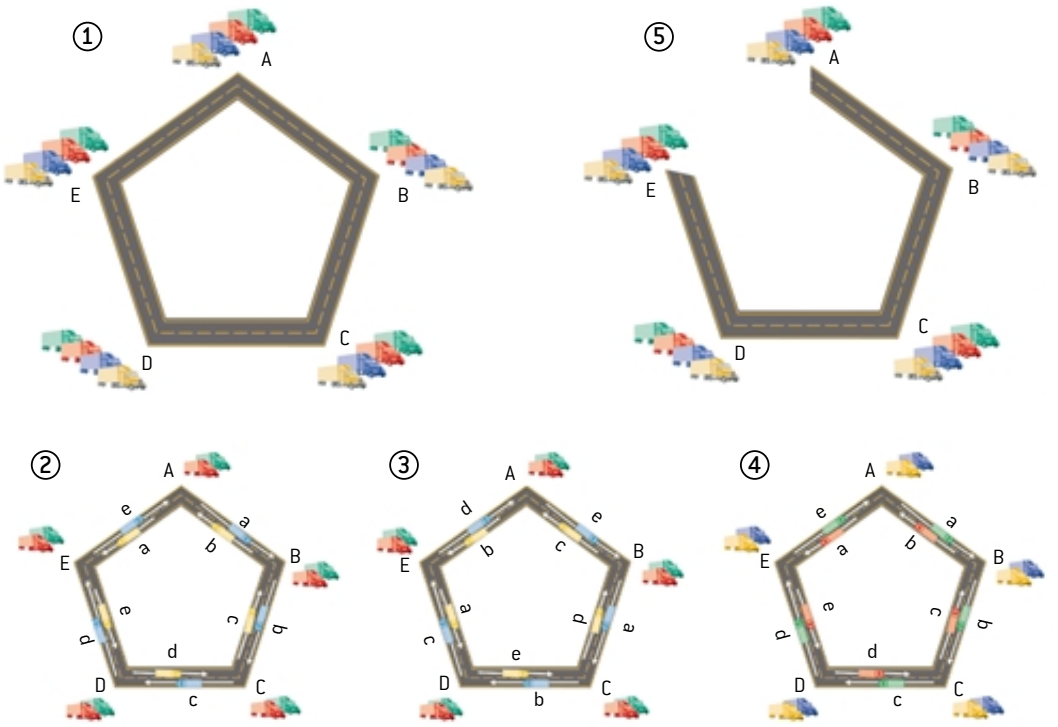
Truck Stop

BY DENNIS E. SHASHA

In a European country famous for its art, wine and revolutions, a group of truckers figured out how to demand lower fuel prices. They simply blocked roads and dared anyone to pull them out of the way. This puzzle is dedicated to them.

Consider a pentagonal road network having two lanes between each of the pentagon's vertices [*see illustrations below*]. Suppose a truck can travel from one vertex to its neighbor in one minute. While that happens, no other vehicle can use the same lane in either direction. In this puzzle, four delivery trucks start at each vertex. Each vehicle then travels to one of the other four vertices; for example, the four trucks from vertex A must end up at vertices B, C, D and E. As a warm-up problem, can you design a routing schedule that ensures that every truck reaches its destination in three minutes or less? The answer is shown in illustrations 1 through 4 below.

The problem becomes more complicated, however, when the truckers stage a demonstration. Suppose that a striker blocks the two lanes between vertices A and E [*see illustration 5*]. In that case, how fast can you have the delivery trucks reach their destinations? And can you prove that your solution is the fastest possible? SA



FOUR TRUCKS begin at each vertex of the pentagon (*1*). In the first minute, one truck from each vertex travels in the clockwise direction in the outer lane, while another truck from each vertex moves counterclockwise in the inner lane (*2*). In the second minute, the trucks in the outer lanes travel clockwise once more to reach their destinations, while the trucks in the inner lanes do likewise in the counterclockwise direction (*3*). In the third minute, one of the two trucks left behind at each vertex travels clockwise in the outer lane, while the other moves counterclockwise in the inner lane (*4*). The solution also works if all the directions are reversed. But what if some of the lanes are blocked (*5*)?

IAN WORPOLE

Answer to Last Month's Puzzle

To maximize the odds of survival, each prisoner follows this rule:

"If I see two red crowns, I say that mine is blue, and if I see two blue crowns, I say that mine is red. Otherwise I pass."

Clearly, there will always be at least two red crowns or two blue crowns.

If there are at least two reds, four possibilities arise:

1. A and B alone are red. Then A and B will pass. C will say blue. Correct.
2. B and C alone are red. B and C pass. A will say blue. Correct.
3. A and C alone are red. A and C pass. B will say blue. Correct.
4. A, B and C are red. All will say blue, and all will be incorrect.

A similar argument applies when there are at least two blue crowns. So the rule ensures that the prisoners will win 75 percent of the time.

If the prisoners can bet different numbers of points, they should agree beforehand who will bet first, second and third. The first prisoner should always bet one point that his crown is red. If the second prisoner sees that the first prisoner has a blue crown, he should bet two points that his crown is red; otherwise he should pass. If the third prisoner sees that the first two prisoners both have blue crowns, he should bet four points that his crown is red; otherwise he should pass. Unless all three prisoners have blue crowns (a 1-in-8 chance), the prisoners will win.

Web Solution

For a peek at the answer to this month's problem, visit www.sciam.com

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The World of Ag Biotech

THEY SHALL BEAT THEIR PETUNIAS INTO PORK CHOPS **BY RICK WEISS**



LORDS OF THE HARVEST: BIOTECH, BIG MONEY, AND THE FUTURE OF FOOD
by Daniel Charles
Perseus Publishing, 2001
($26)

It was 1981, and California scientist Martin Apple was showing visitors his new, futuristic enterprise: the International Plant Research Institute, one of the world's first biotechnology companies devoted to agriculture. The biotech gold rush was just getting started, and Apple, talking about his plans to revolutionize agriculture, confided enthusiastically to a *New York Times* reporter, "We are going to make pork chops grow on trees!"

"When that quote appeared in the newspaper Apple was mortified," writes Daniel Charles in *Lords of the Harvest,* his fascinating and thoroughly reported book about the science, business and politics of agricultural biotechnology. "He meant, of course, that engineered plants might produce the same nutrients that one finds in a pork chop, not an actual hunk of meat hanging on a tree. Besides which, as an observant Jew, he'd never touched a pork chop in his life." Apple even called the chairman of his board to see how they might get the *Times* to print a correction. "Don't worry about it," he told Apple. "It's great publicity."

Ah, those were the days. The days before biotech crops were vilified as "Frankenfood." Before night raids on test plots of genetically modified trees. Before tortilla chips and corn muffins were tainted with gene-altered StarLink corn, approved only for animals because of human health concerns but inadvertently (and inevitably, critics would aver) homogenized into the human food supply soon after its introduction as cattle feed.

It was a time so full of promise and unlimited potential that at Monsanto—the company that would later become the 800-pound gorilla of ag biotech but which was then an old-fashioned chemical giant just starting to experiment with genes—the main biotech research area on U Building's 4th floor had been nicknamed "U-4ia." It was also a difficult time of transition for the old-school Monsanto chemists and agricultural division reps, who felt threatened by the new laboratories full of red and white petunias—the plants that gene engineers were practicing on—and who expressed their fears as ridicule. At a Monsanto Christmas party in 1984, writes Charles in one of his numerous insider vignettes, one scientist brought a mocked-up picture of a petunia-leaf salad with the caption: "New Marketing Strategy: Eat More Petunias!"

Most of all it was a time of discovery and intellectual adventure. Charles, a science reporter who has been a technology correspondent for National Public Radio and for *New Scientist* magazine, relates many of these adventures in wonderful detail. One of my favorites is the tale of how scientists invented a device resembling a BB gun that shot new genes into plants by blasting them with tiny DNA-coated tungsten pellets. Wearing white lab gowns and booties, they tested their invention by strafing onion after onion until the lab was reeking and dripping with onion puree. Their colleagues laughed, but it worked. So did a competing team's version, which used a 25,000-volt charge and some Mylar from a potato chip bag.

Charles's descriptions of seed-company business deals sometimes left me a little confused, and at times his chronol-

BRITISH POLICE lead away protesters who were destroying genetically engineered oilseed rape plants.



NICK COBBING *David Hoffman Photo Library*

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ogy of biotech's advancement got hard to track—an unavoidable shortcoming, perhaps, in a book organized (and rightly so) by topic instead of time. Laudably, however, and unlike many of the books already out on this subject, *Lords* is not a piece of political hatchetry bent on slicing and dicing biotech foods into Veg-O-Matic oblivion. Indeed, Charles is sympathetic to the industry side of the debate. A number of the scientists who gave birth to ag biotech were children of the sixties, he notes. Sure, they were arrogant as hell. But they really did believe that genetic technology might feed the world, clean the world, change the world.

Yet Charles is not an apologist for Monsanto and the other corporate generals in the ag biotech business. He offers a collection of telling anecdotes that reveal the leading scientists and entrepreneurs in the industry as aggressive and even ruthless competitors who were not above stealing ideas and intellectual property from one another and who repeatedly put their own economic interests ahead of the world they had promised to save. On at least one occasion a scientist went so far as to aseptically shred documents received from a competing lab and to culture the bits of paper in petri dishes, hoping the paper might carry a few cells containing the competitor's valuable proprietary genes. Charles also subjects to rigorous analysis Monsanto's claim that its high-tech seeds are going to help poor farmers in the developing world and concludes along with the industry's opponents that, on the whole, the claim is false.

In one enlightening chapter, Charles describes an extraordinary but little-known series of private retreats attended by high-ranking proponents and opponents in the early 1990s. Coordinated by Berlin sociologist Wolfgang van den Daele, the meetings helped to reveal what many had until then been unwilling to admit: the dispute over gene-altered food was about much more than human health and the environment; it was rooted in deeply conflicting views about democracy, capitalism and global trade. In the end, the meetings broke down, with industry claiming that opponents were unwilling to admit to having a larger revolutionary agenda and opponents claiming that industry was using those unresolvable issues to paper over biotech's problems immediately at hand.

History, I suspect, will ultimately agree with Charles that in this respect both sides were right. SA

Rick Weiss writes about science for the Washington Post.



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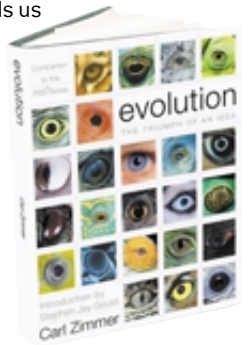
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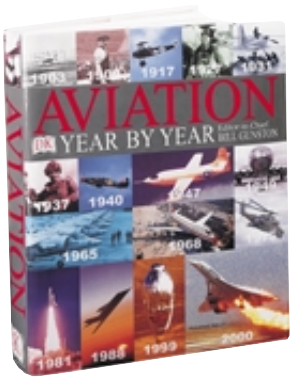
THE EDITORS **RECOMMEND**

EVOLUTION: THE TRIUMPH OF AN IDEA
by Carl Zimmer. HarperCollins, New York, 2001 ($40)

"In late October 1831 a 90-foot coaster named the HMS *Beagle* lay docked at Plymouth, England. Its crew scrambled about it like termites in a nest...." Proceeding from the flurry of preparations for Darwin's famous voyage, Carl Zimmer leads us off on a journey of our own, tracking the development—and the implications—of one of the most powerful ideas in the biological sciences. Written as a companion to the WGBH/Nova seven-part television series that aired in late September, the book and the show itself aim to bring the contentious debate about evolution to a wide audience.



Zimmer, who was an editor at *Discover* magazine and is the author of *At the Water's Edge* and *Parasite Rex,* writes in a gloriously clear and lively style. But don't be misled by the polished prose, the gorgeous illustrations, the elegant design or the book's status as a "companion volume": Zimmer neglects neither underlying biological concepts nor current controversies. His coverage is as thorough as it is graceful. This is as fine a book as one will find on the subject.

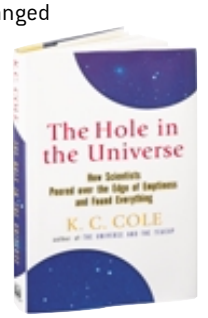


AVIATION YEAR BY YEAR
Bill Gunston, editor in chief. DK, London, 2001 ($50)

The time line for this illustrated history of aviation begins at "c. 1500," when Leonardo da Vinci sketched plans for several flying machines. It proceeds through 1999, the year of the first nonstop circumnavigation of the earth by balloon. The accompanying text, which carries the history through 2000, is presented as if the events had been reported in newspaper articles. From 1900 on, the accounts proceed year by year. All this, abetted by many fascinating pictures, makes the book eminently rewarding.

THE HOLE IN THE UNIVERSE: HOW SCIENTISTS PEERED OVER THE EDGE OF EMPTINESS AND FOUND EVERYTHING
by K. C. Cole. Harcourt, New York, 2001 ($24)

Cole, a science columnist for the *Los Angeles Times,* provides an illuminating slant on physics and mathematics by exploring the concept of nothing. "In the past few hundred years," she writes, "the struggle to get a handle on nothing has changed the course of mathematics, physics, and even the study of the human mind." Indeed, the doors to many scientific breakthroughs are "holes in the understanding, gaps in the data." Scientists search for such nothings as missing matter, missing neutrinos and missing magnetic monopoles because "finding the missing pieces helps to prove—or disprove—the theories that suggest these entities should exist in the first place." Something, therefore, is "any deviation from nothing," and each deviation adds to the store of human knowledge.



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BETH PHILLIPS

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Dumb, Dumb, Duh Dumb

A BRIEF COLLECTION OF ANECDOTAL EVIDENCE TO SUPPORT THE NOTION THAT "A LITTLE KNOWLEDGE" WOULD IN ACTUALITY REPRESENT MAJOR PROGRESS **BY STEVE MIRSKY**

The need for improvement in our nation's math and science education is a standard sentiment of our times. Indeed, a close scrutiny of recent news headlines, combined with a personal experience, indicates to me that our nation's math and science skills truly have plummeted to a value of *x*, where *x* is some number that is very, very low.

For example, consider the story of four young men who busted into a veterinarian's office in Noblesville, Ind., in late August. The ne'er-do-wells were nailed after stealing what they thought was a painkiller known as OxyContin, which has gotten press lately because some idiots snort it to achieve a heroinlike high. Our callow dopes, however, apparently have an attention span of only three letters, for what they stole was in fact oxytocin, which helps females give birth, produce milk and develop nurturing feelings toward their progeny. As the editor of a major American scientific magazine said after I told him about the confused criminals, "Maybe I'm wrong, but you've got to think that four young guys with enlarged, tender nipples and a tendency to cuddle are not going to fare that well in prison."



Just a few days before the aforementioned arrests came another example of the challenges faced by those who possess an IQ of *x*, where *x* is some number that is very, very low. This case concerned a Long Island woman who allegedly decided to end her marriage to her millionaire husband the old-fashioned way—by killing him. The flaws in her plan, however, were more fatal than the plan itself. An aide at a nursing home, the woman told her husband she needed him to help her practice drawing blood. She would, therefore and henceforth, regularly be sticking needles in his arm. But unbeknownst to him, she was shrewdly using dirty needles smuggled out of the nursing home, in the hopes of giving him AIDS.

How greatly she might have benefited from a sound science education. For one, AIDS is not exactly rampaging through nursing homes, so the odds of her bringing home a needle carrying HIV were slim. For another, it is extremely rare to get infected with HIV even after being stuck with a needle that has been in contact with HIV-positive blood: the transmission frequency is only about 0.3 percent. The woman, who merely succeeded in giving her husband more common and easily transmissible conditions, such as hepatitis, was caught after she ran out of patience and tried to hire a hit man to expedite matters. The hit man turned out to be a police informant, and the woman and her husband are now, one might say, legally separated.

Finally, also in late August, I found myself stuck in southbound traffic on the infamous elevated Bruckner Expressway in the beautiful Bronx. This traffic jam was special, as it consisted in large part of people who were ignorant, or at least apathetic, about mathematics. They were returning from Connecticut, which was selling tickets for the $295-million Powerball lottery, to New York, which does not. A few days later I expressed my frustration to Michael Orkin, professor of statistics at the California State University at Hayward and author of *What Are the Odds? Chance in Everyday Life*. He e-mailed back, "If you have to drive 10 miles to buy a Powerball ticket, you're 16 times more likely to get killed in a car crash on your way than you are to win." Share this statistic with any of the geniuses on the Bruckner, and they might say, "But we weren't on our way. We were on our way *back*." Besides, with the road so clogged, any crashes would have occurred at a survivable *x* miles per hour, where *x* is some number that is very, very low. SA

ILLUSTRATION BY MATT COLLINS; PHOTOGRAPH BY FRANK VERONSKY

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Does the appendix serve a purpose in any animal?

—N. Roberts, London

Julie Pomerantz, wildlife veterinarian and program officer for the Wildlife Trust's North American Conservation Medicine Initiative, offers the following explanation:

As a specific anatomical structure, the appendix has been described in only a few species. In humans and apes it is thin and tubular (hence the name "vermiform," meaning "wormlike," appendix) and located at the apex of the cecum, a blind pouch near the beginning of the large intestine. In adult humans the appendix is best known for its tendency to become inflamed, necessitating its surgical removal. Scientists have identified appendixlike structures in other species of primates, but those have not been well characterized. Rabbits and some rodents also have appendixes, and it is research on these species that has begun to unravel the mystery of the organ's function.



EDISON: THE EARLY YEARS

Previously it was thought that the saclike rabbit appendix served primarily as a reservoir for the bacteria involved in hindgut fermentation. That explanation, however, did not account for the absence of an appendix in other animals with similar digestive systems or for its presence in humans. When researchers examined the appendix microscopically, they found that it contains a significant amount of lymphoid tissue. Similar aggregates of lymphoid tissue occur in other areas of the gastrointestinal tract and are known as gut-associated lymphoid tissues. The functions of gut-associated lymphoid tissues are poorly understood; however, it is clear that these tissues are involved in the body's ability to recognize foreign antigens (molecules to which the immune system can respond) in ingested material.

Thus, although scientists have long discounted the human appendix as a vestigial organ, a growing quantity of evidence indicates that the appendix does in fact have a significant function as a part of the body's immune system. The appendix may be particularly important early in life because it achieves its highest state of development shortly after birth and then regresses with age, eventually coming to resemble such other regions of gut-associated lymphoid tissue as the Peyer's patches in the small intestine. The immune response mediated by the appendix may also relate to ulcerative colitis and other inflammatory conditions. SA

For the complete text of this and many other answers from scientists in diverse fields, visit Ask the Experts (www.sciam.com/askexpert).

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PATRICK HARDIN

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